FINAL REPORT

FOR

ARB AGREEMENT A8-119-31

Air Pollution Effects on Yield, Quality and Ecology of Range and Forage Grasses

V. B. Youngner, F. M. Shropshire, O. C. Taylor and R. B. Flagler

Department of Botany and Plant Sciences

University of California

Riverside, CA 92521

2 December 1981

ABSTRACT

In order to determine the effects of chronic exposure to ozone and sulfur dioxide on yield and forage quality, seven forage and seven range grasses were exposed to various levels of the pollutants in closed fumigation chambers. Ozone levels were 100, 67, 33, and 0 percent of ambient. Sulfur dioxide was supplied at 10 pphm. The interaction of pollutants and defoliation was also investigated. Yield parameters studied were total forage dry weight, tiller production and dry weight per tiller. The quality parameters were forage content of nonstructural carbohydrates, crude protein, crude fiber, calcium, magnesium and phosphorus.

Chronic ozone exposure affected yield in varying degrees in all of the forage grasses. Effects were also observed on all quality parameters but species differed in their responses. The most pronounced response was in soluble carbohydrate levels. In general, cool-season grasses showed greater effects from ozone than warm-season species. Sulfur dioxide effects were more limited. Pollutant interaction was noted only in one case. At the end of the treatment period, interactions between pollutant exposure and simulated grazing (defoliation) were found for yield and some mineral components in several species.

Similar but less pronounced effects were noted for the range species, however, significant pollutant interaction was noted in two species. Pollutant-defoliation interaction was also observed in two species. Ambient ozone levels were markedly lower during this study period than they were during the forage study. Because species differed in their growth responses to the pollutants, possible changes in species composition of natural grasslands subjected to air pollution must be considered.

TABLE OF CONTENTS

LIST OF TABLES

ACKNOWLEDGEMENTS

Successful completion of this project was clearly dependent upon the cooperation and efforts of many persons.

C. K. Labanauskas (Dept. of Botany and Plant Sciences) and Isfen Ramadan (Cooperative Extension Laboratory) generously provided the equipment required for many of the chemical analyses. Use of greenhouse space was arranged through the cooperation of C. Ray Thompson.

The stalwart assistance of Barbara Pfrunder throughout the field and laboratory phases was indispensable and is greatly appreciated. Analysis of carbohydrate samples was most efficiently expedited by Frank Nudge. Others whose efforts are clearly deserving of recognition are Marcia Bastian, Lisa Ciano, Charles Filmer, Ahmad Hashemi, Mohommed Khair, Kevin Kieswetter, Matt Leonard, Mark Mahady, Pat O'Scannell, Alice Ricker, and Robert Rogers.

For their guidance in all phases of the study we are indebted to our contract officers Bob Reynolds, Barbara Jost, Dane Westerdahl, and John Sanders.

Special thanks are given to Meg Gale and, especially, Gail Lee for patience and good humor in typing the final report.

This report was submitted in fulfillment of Air Resources Board Contract No. A8-119-31, "Air Pollution Effects on Yield, Quality and Ecology of Range and Forage Grasses," by the Regents of the University of California under the sponsorship of the California Air Resources Board. Work was completed as of 30 April 1981.

SUMMARY AND CONCLUSIONS

In order to study the effects of air pollutants on yield and quality of range and forage grasses, two similar experiments were conducted in 4 x 2 factorial designs using 100, 67, 33, and 0% filtered ambient air for oxidant levels and 0 and 10 pphm SO_2, with two replications of each treatment. In the first experiment seven forage grasses were studied: Lolium perenne (perennial ryegrass), Dactylis glomerata (orchardgrass), Phleum pratense (timothy), Phalaris arundinacea (Reed canarygrass), Festuca arundinacea (tall fescue), Paspalum dilatatum (Dallisgrass) and Cynodon dactylon (Bermudagrass). In the second experiment, seven annual range grasses were studied: Avena barbata (slender wild oats), Bromus mollis (soft chess), B. rubens (red brome), B. rigidis (ripgut grass), B. tectorum (downy chess), Festuca megalura (foxtail fescue), and Hordeum leporinum (mouse barley).

Secondary experiments with the same species in 2 x 2 factorial designs (using 33 and 100% filtered ambient air with 10 and 0 pphm SO_2, respectively) in which the grasses were clipped at regular intervals were used to study the effects of the interaction of the pollutants with grazing.

Yield parameters studied were shoot dry weight, tiller (shoot) production, and dry weight per tiller. Quality parameters were forage content of nonstructural carbohydrates, crude protein, crude fiber, and the minerals calcium, magnesium, and phosphorus.

Significant results obtained from the study included:

1. Gram dry weight yield was affected in varying degrees by ozone with 10-20% reductions observed at the highest (unfiltered) level in the forage grasses Lolium, Phleum, Paspalum, and Cynodon. Reductions of over 16% were observed in the range grasses Bromus rubens and Festuca megalura.

2. Tiller production was reduced by ozone in several species, most notably, Festuca arundinacea, Lolium perenne, Dactylis glomerata and Phleum pratense.

3. Nonstructural (soluble) carbohydrate levels were reduced by ozone in all forage species and to a lesser extent in the range species.

4. In general, crude protein levels were increased by ozone exposure.

5. Crude fiber was generally increased by ozone exposure indicating a possible reduction in digestibility.

6. Mineral content was variously affected in both forage and range species by ozone exposure and did not present a clear trend.

7. Sulfur dioxide alone showed fewer effects, with changes in levels of soluble carbohydrate and crude protein being most evident. Ozone-SO_2 interactions were observed in crude protein, carbohydrate, and crude fiber content in certain species.

8. Defoliation and pollutant interactions affecting carbohydrate, phosphorus, and magnesium content and weight per tiller were observed in several range and forage species.

9. Species varied widely in their individual responses to all of the parameters studied. This may have implications relative to compositional changes in natural grasslands.

RECOMMENDATIONS

During the course of this investigation a number of questions have arisen which form the basis for the following recommendations.

1. What are the responses of these species at known ozone levels? Responses based on dilutions of ambient air are useful in determining if a problem actually exists under natural atmospheric conditions. However, ambient air is a mixture of gases whose component gases and levels vary daily; indeed, a mixture whose component gases have not yet all been identified. Therefore, additional studies at known ozone levels are recommended.

2. What are the responses of these species to other levels of SO_2? Do they change? Information in the literature indicates that beneficial effects noted at low SO_2 levels are often reversed at higher levels. Studies are called for to investigate this possibility and determine thresholds if such effects are indeed found.

3. Further study of pollutant interaction in these species is desirable:

   a. Use of a 3 x 3 factorial design might be useful in quantifying the interaction term.

   b. What is the effect of various pollutant dosage ratios on plant responses? Ozone-sulfur dioxide ratios were quite different during the forage and range fumigations. Is this in any way linked to the observation that more suggestions of pollutant interaction were found among the range grasses? Explorations of the effects of different pollutant dosage ratios on plant response are clearly indicated.

4. What are the effects of these pollutant-induced decreases in carbohydrate content on the biology of the plant? Is the life cycle of the grass altered? Successful flowering and seed production are heavily dependent upon adequate carbohydrate levels, therefore decreased carbohydrate levels might well have deterimental effects upon reproductive ability. Studies of carbon-allocation (partitioning) in the presence of pollutant(s) would be a first step in addressing this question.

5. The question of grazing-pollutant interaction has barely been touched:

   a. What effects do these pollutants singly have on defoliation responses? Mixed gas fumigation was used in this pilot study, thus no separation of pollutant effects was possible. Such separation is important in light of indications that SO_2 may be ameliorating ozone effects in some species. Thus, clipping-pollutant studies involving single gas exposures are recommended.

b. What is the effect of growth stage on grazing-pollutant interaction? The results discussed here are based only on end-of-season comparisons. Data collected incidental to this study suggest that earlier stages of growth might be more susceptible to such effects. Studies on grazing pollutant interaction at different stages of the grass life cycle are therefore indicated.

6. Some of the species investigated showed pollutant response trends which did not reach statistical significance at the 5% level:

a. Would in-depth studies bear out these trends?

b. Are range grasses truly less susceptible to air pollutants or were the pollutant levels (especially of ozone) during this study below threshold levels? Future studies should clearly include pollutant levels that exceed ambient concentrations in order to address this problem.

7. Will these species show similar responses under more natural or field conditions?

a. Climatological considerations. Closed-top chambers are essentially an artificial environment with attendent alterations in parameters such as temperature and relative humidity. Some departures from ambient were noted in this study. It is important that pollutant effects now be determined under conditions which more nearly approximate nature.

b. Biological considerations. The comments on possible compositional changes in natural grasslands are based on differential species responses when grown in essentially pure stands. This is a very unnatural condition. Future studies should include investigation of responses with mixed stands, ultimately including the forb component.

INTRODUCTION

California has over 35 million acres in grazinglands of which 9.8 million acres are grasslands per se and 7.5 million acres are woodland grassland (primarily oak woodland). In addition, there are 1.3 million acres of irrigated pasture and 520,000 acres of non-alfalfa hay. On all of these areas grasses are the principal or at least an important constituent, providing a valuable source of forage for California's huge livestock industry.

Although air pollution is a problem over a large part of these lands, at the time this study was initiated little information was available on the effects of air pollutants on forage and range grasses. Most of the studies that had been reported were concerned with pollutant levels and environmental conditions required to produce visible leaf injury in various genera, species and cultivars (Brennan and Halisky, 1970; Wilton et al, 1972; Price and Treshow, 1972; Hill et al, 1974; Murray et al, 1974; Youngner, 1975). Although valuable, little of this type of information is of direct relevance to the concerns of California stockmen or to the agencies formulating air pollutant policy.

In order to set appropriate standards which will safeguard the interests of this vital sector of the economy, the state regulatory agencies need information on the effects of pollutants on yield and forage quality. However, little of the information required was available and what there was tended to be confusing and contradictory. Of the reports concerned with yield or biomass two had considered range species and four had dealt with cultivated forage grasses. Davis et al (1966) found no detrimental effects on yield of 3 southwestern range grasses subjected to 4 growing-season fumigations at unspecified SO_2 levels. Price and Treshow (1972) reported significant biomass (yield) reduction in 6 native species subjected to chronic O_3 exposure. Data from this laboratory (Youngner and Nudge, 1980) also showed growth reduction from chronic O_3 fumigation in 4 forage/turf species. Data from English investigators (Bleasdale, 1952; Bell and Clough, 1973; Lockyer et al, 1976) working with SO_2 and the forage grass *Lolium perenne* cast doubt on the findings of Davis et al (1966). Bell and Clough, for example, found a 46% decrease in yield from exposure to 13 pphm SO_2 for 9 weeks.

Tiller development is another important aspect of productivity. Decreases in tiller number following chronic exposure to SO_2 had been reported by Bell and Clough (1973) in perennial ryegrass and by Heck and Dunning (1978) in oats (*Avena sativa*). Bennett and Runeckles (1977) reported no effects from low O_3 levels on Italian ryegrass (*Lolium multiflorum*). Work in this laboratory (Youngner and Nudge, 1980) indicated that tiller response may vary with the species; tillering decreasing, increasing, or remaining unaffected depending upon the species.

There was practically no information on the effects of pollutants on quality or chemical composition of forage and range grasses. The work of Davis et al (1966) led them to conclude that there were no detrimental effects from SO_2 fumigations. Although there were no published reports on O_3 effects on grass quality, some data were available from other crops. Dugger et al (1966) and Dugger and Palmer (1969) showed a reduction in total carbohydrates in citrus from chronic O_3 exposure. On the other hand, ozone-induced increases in foliage levels of soluble carbohydrates had been reported in both soybean and ponderosa pine (Miller et al, 1969; Barnes, 1972; Tingey, 1974).

Decreased foliage protein levels after O_3 fumigation had been reported by Ting and Mukerji (1971), Craker (1972), and Tingey (1974). Increased foliage protein levels had been recorded in other reports (Bennett, 1969; Tingey et al, 1973; Tingey and Neeley in Tingey, 1974). None of these studies involved grasses.

The only information available on air pollutant effects on mineral composition was a short report by Faller (1970-71) which showed that chronic SO_2 exposure influenced calcium, potassium and magnesium content in sunflower, tobacco and corn.

No reports had been found on air pollutant effects on percent digestibility.

The effects of grazing in combination with air pollutant pressures on the yield and quality parameters discussed above have barely been touched. A clipping study performed in this laboratory on 4 forage/turf species provided the only information to date (Youngner and Nudge, 1980). These data indicated that moderately high O_3 levels may significantly modify both yield and tillering response to defoliation. Since forage and range grasses are subject to regular defoliation during the period of exposure to air pollutants, further information on this interaction was essential.

The matter of synergistic or non-additive interactive effects of these air pollutants on the above grass parameters apparently had never been studied although such responses had been recorded in other crops (Menser and Heggestad, 1966; Tingey et al, 1973).

In light of the above, the following study was initiated in order to provide information of this nature on yield and quality of forage. Such information is of immediate importance in the governmental decision-making required to safeguard California's valuable livestock industry. However, these studies may have profound ecological implications for natural rangelands as well. Differential species responses to these air pollutants could initiate significant compositional changes in the millions of acres of grass and woodland-grass ecosystems. If the more aggressive but less desirable grasses (from a forage viewpoint) are more tolerant of the air pollutants serious degradation of range and watershed could occur in time.

In summary, it is intended that data from the studies herein described would aid in determining dose-response relationships of 14 grass species of major importance in our California rangelands and pasture. Such data could then help provide a basis for predicting potential areas of harm to grassland vegetation (including long-term effects on ecosystem composition) which would be of vital concern in power plant siting, future land use planning and in formulation of regulatory agency policy for these areas.

PROJECT OBJECTIVES

Objective 1: To determine the yield of selected range and forage grasses as affected by chronic exposure to SO_2 and O_3. Yield was measured in terms of dry weight and tiller production.

Objective 2: To determine the effects of chronic exposure to SO_2 and O_3 on the forage quality of these grasses. Particular attention was given to soluble carbohydrates, protein, mineral constituents, and digestibility.

Objective 3: To determine the effects of any interaction of these pollutants with grazing (defoliation) on the above yield and quality parameters.

Objective 4: To determine differential species responses to these pollutants which might affect future compositional changes in natural grasslands.

MATERIALS AND METHODS

A. Fumigation facility

The ambient fumigation facility located at the University of California, Riverside campus and administered by the Statewide Air Pollution Research Center (SAPRC) was used for these studies. This facility was constructed under ARB Agreement A6-162-30 and consists of 20 teflon exposure chambers arranged in 2 replicate 10 chamber sets. Each set of 10 chambers was linked by a common air handling system composed of ambient and filtered air ducts. An instrument shed for monitoring purposes was centrally located between chamber sets. (See Oshima, 1979, for specific details of chamber construction, air handling system, etc.)

To meet the requirements of this project, the floor space of each of these 7' x 7' constant-stir, closed-top chambers was modified. Specifically, a temporary 12" high retainer wall arranged in a semicircle was set on the floor and filled with sterilized wood shavings. The pots of grasses were then partially buried in the shavings which provided insulation for the root zone.

Chambers were characterized to determine any differences in temperature, relative humidity, and PAR existing between the chambers and the ambient environment. These characterizations lasted from sunup to sundown and were conducted once during each 3 month fumigation period (See Appendices A and B).

Ozone levels during fumigation were monitored with the use of two Dasibi 1003-AH ozone-specific instruments. Prior to use, these instruments had been cleaned and checked against a reference ozone source maintained by SAPRC.

Two ThermoElectron Model 43 SO_2-specific instruments were used to monitor SO_2 levels. These instruments had previously undergone calibration at the Air Resources Board laboratory in El Monte.

Thermocouples within each chamber provided continuous monitoring of temperature. Relative humidity measurements and determinations of levels of photosynthetically active radiation (PAR) were also made. Mean temperature and relative humidity values during the respective fumigations are presented in Table 1.

Table 1. Environmental conditions during fumigation periods.

Fumigation I

Temperature (°C):	Chambers	Air
mean maximum	28.2	28.4
mean minimum	10.1	9.8
Relative humidity (%):		
mean maximum	78.3	70.4
mean minimum	39.8	34.5

Fumigation II

Temperature (°C):	Chambers	Air
mean maximum	30.7	33.7
mean minimum	6.7	5.1
Relative humidity (%):		
mean maximum	78.6	66.8
mean minimum	47.8	32.8

B. Air pollutant exposure

Two separate 12 week fumigations were conducted. The first involved forage species exclusively and lasted from 20 June 79 to 11 September 79 (Fumigation I). Although cool-season species were stressed somewhat by growth under the high temperatures of summer, growing them during this period more closely approximated the natural situation in California. That is, both cool and warm-season grasses are commonly grown under irrigation as supplementary feed during the dry summer period. The second fumigation was conducted from essentially 12 November 79 to 4 February 80 and involved only the winter annual range species (Fumigation II).

Within each fumigation two different types of studies were conducted. The first type was termed the "basic biomass and quality studies" and involved a majority of the chambers. In these investigations a replicated 4 x 2 factorial design was used for fumigation of unclipped specimens of each forage or range species (See Table 2, Exposure Design).

Oxidant exposures of 100, 67, 33, and 0% filtered (100% ambient) were run continuously throughout the 12 week period. Where appropriate, SO_2 exposures at 10 pphm were also conducted. SO_2 fumigations were of 6 hours duration (from 0900 to 1500 PST) and were conducted on 5 consecutive days per week, excluding weekends. (Actual exposure dosages for both Fumigation I and Fumigation II are presented in Tables 3 and 4 - see also Appendix C. For comparisons between chamber levels and ambient values on the three days of highest pollutant levels in each fumigation see Appendices D and E.) Exposure levels were randomly assigned to the chambers within each 10 chamber set.

The remaining four chambers were used for a clipping experiment intended to simulate season-long grazing and these were termed the "grazing simulation studies." Plants in all of these chambers were clipped to a 2" height at 4 week intervals. Two chambers were used for filtered-air controls while the two remaining chambers received fumigation at a moderately high pollutant load; i.e., 33% filtered and 10 pphm SO_2. Unclipped plants in the basic biomass studies were used to simulate a second grazing strategy; i.e., one in which grazing is deferred until late in the season.

C. Plant material and culture

Forage. Plants exposed during Fumigation I consisted of seven species of cultivated grasses commonly used for forage purposes in California. The species chosen for study were:

Perennial ryegrass, *Lolium perenne*	Cool-season grasses
Orchard grass, *Dactylis glomerata*	
Timothy, *Phleum pratense*	
Reed canarygrass, *Phalaris arundinacea*	
Tall fescue, *Festuca arundinacea*	
Dallis grass, *Paspalum dilatatum*	Warm-season grasses
Bermuda grass, *Cynodon dactylon*	

Seed of *Phalaris* was generously provided by Dr. A. W. Hovin of the Dept. of Agronomy and Plant Genetics, University of Minnesota. Seed of all other species was supplied by Northrup-King and Co.

Table 2. Chamber exposure design.

A. Basic biomass and quality studies.

Two chambers at each of the eight following conditions:

Percent filtered ambient air and pphm SO_2	
100 filtered 0 SO_2	100 filtered 10 SO_2
67 filtered 0 SO_2	67 filtered 10 SO_2
33 filtered 0 SO_2	33 filtered 10 SO_2
0 filtered 0 SO_2	0 filtered 10 SO_2

B. Grazing simulation studies.

Two chambers: 100% filtered, 0 pphm SO_2
Two chambers: 33% filtered, 10 pphm SO_2

Table 3. Fumigation I. Calculated pollutant dosages using 7 designated threshold levels for ozone.

Chamber No.	SO_2 Dose (pphm-hr)	Filtered Ambient Air (%)	O_3 Dose (pphm-hr)						
			>0pphm	>3pphm	>5pphm	>8pphm	>10pphm	>15pphm	>20pphm
1	0	67	4735.2	1499.0	491.3	41.8	7.2	0	0
2	0	0	10106.1	6124.6	4258.8	2220.0	1297.9	224.5	23.9
3	0	100	1831.7	18.9	0	0	0	0	0
4	0	100	1973.1	31.2	0	0	0	0	0
5	3075	0	10274.2	6275.5	4383.9	2293.7	1344.4	226.7	25.4
6	0	33	6518.2	2927.8	1496.6	346.9	99.7	1.7	0
7	3072	33	7033.4	3363.9	1842.7	533.9	183.3	7.3	0
8	3068	33	7008.7	3344.1	1822.7	516.3	174.8	6.1	0
9	3070	100	2333.4	95.4	1.7	0	0	0	0
10	3065	67	5676.4	2214.8	952.0	151.6	30.0	0	0
11	0	100	1519.9	2.5	0	0	0	0	0
12	3072	33	7006.3	3357.1	1877.2	562.4	201.5	8.1	0
13	0	100	1499.4	2.2	0	0	0	0	0
14	0	33	7200.5	3523.3	2000.0	631.2	228.2	10.1	0
15	3071	100	1561.6	3.3	0	0	0	0	0
16	3072	33	7380.0	3674.8	2117.3	699.2	259.9	12.2	0
17	0	0	11142.3	7068.9	5110.0	2880.8	1813.3	390.5	50.6
18	3074	0	11477.9	7382.2	5397.5	3116.9	2004.4	468.2	67.1
19	0	67	5493.2	2076.1	850.0	118.8	21.7	0	0
20	3068	67	5908.9	2410.9	1098.5	199.4	41.5	0	0
Ambient	--		11305.0	7220.0	5254.0	3001.0	1906.0	413.0	60.0

Table 4. Fumigation II. Calculated pollutant dosages using 7 designated threshold levels for ozone.

Chamber No.	SO_2 Dose (pphm-hr)	Filtered Ambient Air (%)	O_3 Dose (pphm-hr)						
			>0pphm	>3pphm	>5pphm	>8pphm	>10pphm	>15pphm	>20pphm
1	0	67	1595.4	48.4	9.9	0	0	0	0
2	0	100	714.2	0	0	0	0	0	0
3	0	33	2409.1	152.5	55.1	10.3	0	0	0
4	0	0	3349.7	368.3	157.4	54.8	27.2	0	0
5	2220	0	3389.9	377.1	163.1	56.4	28.3	0	0
6	2217	33	2454.4	154.5	54.8	8.2	0	0	0
7	2215	67	1700.0	55.1	13.3	0	0	0	0
8	2226	100	794.7	0.1	0	0	0	0	0
9	2219	33	2690.8	205.2	81.1	19.9	1.6	0	0
10	0	100	799.7	0.1	0	0	0	0	0
11	2229	100	925.4	2.1	0	0	0	0	0
12	2221	0	3691.7	460.2	199.5	72.1	37.1	0	0
13	0	100	648.84	0	0	0	0	0	0
14	0	67	1891.1	78.6	16.9	0	0	0	0
15	0	100	543.2	0	0	0	0	0	0
16	0	0	3611.2	437.7	191.1	68.5	35.6	0	0
17	0	33	2635.5	187.6	72.1	15.3	0.2	0	0
18	2216	67	1911.2	77.6	19.5	0	0	0	0
19	2213	33	2726.0	205.7	80.7	18.8	0.9	0	0
20	2220	33	2400.6	121.0	45.2	9.0	1.0	0	0
Ambient	--		3935.0	540.0	229.0	84.8	43.0	0	0

Seed was sown directly into one gallon plastic pots containing a uniform soil mix designated as UC Soil Mix III (see Appendix F for specific composition). All pots were located in greenhouses equipped with activated charcoal air filters. Prior to fumigation all pots were thinned to three seedlings per pot. On 30 June 1979 all pots were transferred to the fumigation chambers. At this time the grasses were approximately four weeks old, with 3-6 tillers depending on the species.

Five pots per species (with three plants per pot) were randomly assigned to each chamber. The sample size was thus 15 plants per chamber or, with replicates, 30 plants per treatment.

Polyethylene tubing was attached to each pot and daily irrigation was provided automatically with the use of two Toro 11-station controllers. Fertilizer was applied at four week intervals in the form of dissolved ammonium sulfate at a rate equivalent to commercial application rates.

Range. Fumigation II involved seven species of annual grasses important in California grass and woodland-grass ranges. Species selected for study were:

Slender wild oats, *Avena barbata*
Soft chess, *Bromus mollis*
Ripgut grass, *Bromus rigidis*
Red brome, *Bromus rubens*
Downy brome, *Bromus tectorum*
Foxtail fescue, *Festuca megalura*
Mouse barley, *Hordeum leporinum*

In so far as possible, seed was field collected from areas receiving minimal air pollutant exposure. Seed of *Bromus mollis*, *B. rigidis*, and *B. tectorum* was obtained at Maloney Canyon on the eastern, desert slope of the San Bernardino Mountains. *Festuca megalura* seed was collected in the Antelope Valley in the desert east of the San Gabriel Mountains. Seed of *Avena barbata* was gathered at Pt. Mugu State Park on the coast approximately 40 km north of Los Angeles. However, due to time constraints and inability to locate outside populations with viable seed, seed of *Bromus rubens* and *Hordeum leporinum* was collected on the UCR campus.

Seed of these species was not sown directly into the pots since a dormancy factor was involved. Cleaned seed was placed on filter paper over moistened vermiculite in plastic containers and these units were then placed in a cold temperature ($\underline{+}$ 10°C) room for approximately one week. Individual seeds were then hand placed in each pot which, as before, was located in greenhouses equipped with activated charcoal air filters and which contained UC Soil Mix III. The seeds germinated quickly with this treatment and pots were transferred to the fumigation facility when the grasses were approximately two weeks old. However, after 9 days of oxidant exposure and 3 days of SO_2 exposure, strong Santa Ana winds seriously damaged many of the chambers and the fumigation was brought to a halt. The chambers were immediately repaired and fumigation was reinitiated on 12 November 1979. At this time the plants were approximately five weeks old.

A comparable sample size was used in this portion of the experiment; i.e., 3 plants per pot, 5 pots of each species per chamber.

Irrigation was provided by means of the same automatic system; however, since this experiment was conducted during a cooler season, watering was done on alternate days for a shorter period of time.

Fertilizer was applied to these species only once, in the same form and rate as described above.

Aphid infestation of these species was noted on 10 December 79. Orthene was applied 12 December 1979 and no further infestations occurred.

D. Plant parameters studied.

At the end of the 12 week fumigation periods all above-ground portions of the grasses were harvested and dried in a forced-air oven at 65-70°C for at least 72 hours. Determinations were then made of total gram dry weight yield of stems, leaves and seeds per pot and number of tillers was counted.

Subsequently all samples were hand-chopped and a 5 gram subsample ground through a Wiley mill at 40 mesh. This material was then used for the following determinations:

1. Protein content. This information was obtained by first analyzing the sample for percent nitrogen content using the microKjeldahl technique (AOAC, 1980; method 47.021). This method was modified in that selenium was used as the catalyst in place of mercury and H_2SO_4 was used for titration rather than HCl. The resulting nitrogen value was then used to calculate crude protein content according to the formula percent N x 6.25 = percent crude protein (AOAC, 1980; method 7.015).

2. Soluble carbohydrate content. Standard AOAC procedures (AOAC, 1980; method 31.052) for determining total nonstructural carbohydrates were followed. For the analysis of the warm season species the variation using Clarase (takadiastase) was employed (AOAC, 1980; method 7.031, as modified by Smith, 1969).

3. Percent digestible dry matter. Values for this parameter were based on percent crude fiber determinations conducted according to the standard AOAC procedure (AOAC, 1980; method 7.061).

4. Mineral composition. Calcium and magnesium values were determined by atomic absorption spectroscopy using a Perkin-Elmer Model 303 spectrophotometer. Standard AOAC methods were used (AOAC, 1980; method 7.091) with the modification that strontium was used in place of lanthanum to prevent interference from phosphorus. Phosphorus was determined colorimetrically (AOAC, 1980; method 7.120).

E. Statistical analyses

All variables were subjected to standard analysis of variance procedures with treatment sums of squares partitioned into linear and curvilinear contrasts. Regression analysis was performed on all variables exhibiting significant linear or curvilinear trends. Correlation matrices for all dependent variables were also calculated.

RESULTS

For purposes of clarity, data for the forage grass species and range grass species will be considered independently. However, discussion in both cases will be structured around the four project objectives stated in the introduction.

Data in this section will be presented according to the following formats:

1. Basic biomass and quality study tables.

A. Means.

Combination	Count per mean	Subclass	Species
		B O S	
Block (B)			See Note.
Ozone (O) - 100% filtered air			
67% filtered air			
33% filtered air			
0% filtered air			
Sulfur dioxide (S) - 0 pphm			
10 pphm			
Ozone-sulfur dioxide interaction (O x S)			

Means followed by different letters (within a column are significantly different at $p < 0.05$ (lower case letters) or $p < 0.01$ (capital letters) according to Duncan's multiple range test.

B. Sources of variation (with associated df) and mean squares.

Source	Degrees of freedom (df)	Species
Block (B)		
Ozone (O)		
Linear ozone response (O_L)		
Quadratic ozone response (O_Q)		
Cubic ozone response (O_C)		
Sulfur dioxide (S)		

Ozone-sulfur dioxide interaction (O x S)

Linear ozone response interacting with sulfur dioxide (O_L x S)
Quadratic ozone response interacting with sulfur dioxide (O_Q x S)
Cubic ozone response interacting with sulfur dioxide (O_C x S)

Error

Coefficient of variation (C.V. - %)

ANOVA designations of levels of probability.

2. Basic biomass and quality study summary tables.

Format essentially identical to above except in one area. Species headings have been replaced by parameter headings. In the forage grass studies these parameter headings have been further subdivided into responses of cool-season species (Cool) and warm-season species (Warm).

3. Grazing simulation study tables.

A. Means.

Combination	Count per mean	Subclass	Species
		B P C	
Block (B)			
Pollutants absent (P -)			
Pollutants present (P +)			
Clipping absent (C -)			
Clipping present (C +)			
Pollutant-clipping interaction (P x C)			

B. Sources of variation (with associated df) and mean squares.

Source	Degrees of freedom (df)	Species
Block (B)		
Pollutants (P)		
Clipping (C)		
Pollutant-clipping interaction (P x C)		
Error		
Coefficient of variation (C.V. - %)		

ANOVA designations of levels of probability.

Note: Species are abbreviated as follows:

Forage grasses	Range grasses
Lolium perenne = LOL	Avena barbata = AB
Dactylis glomerata = DAC	Bromus mollis = BM
Phleum pratense = PHL	B. rubens = BR
Phalaris arundinacea = PHA	B. rigidis = BRI
Festuca arundinacea = FES	B. tectorum = BT
Paspalum dilatatum = PAS	Festuca megalura = FM
Cynodon dactylon = CYN	Hordeum leporinum = HL

FORAGE GRASS SPECIES

Yield factors

Gram dry weight yield. In four of the seven species studied (Lolium, Phleum, Paspalum, and Cynodon) gram dry weight yield at the highest oxidant exposure was reduced 10-20% over that at the most filtered level (Table 5). In the three remaining species (Dactylis, Phalaris and Festuca), yield increases of 8-26% were registered in a similar comparison. Yield differences for Lolium and Festuca were statistically significant at $p < 0.05$.

In terms of physiological type (Table 8), the warm-season grasses both recorded substantial reductions in biomass at the high oxidant level with the mean decrease being 17.5%. No such uniformity was found in the cool-season species. Indeed, when all five of these species are lumped a mean yield increase of 5.8% is indicated. However, one must keep in mind that no atempt was made to assess these species in terms of visual injury. Thus, apparent increases in yield may in fact reflect a larger proportion of dead leaves with subsequent regrowth. This was quite probably the case in Dactylis where an apparent 17.0% increase in gram dry weight was registered at the highest oxidant level.

Gram dry weight yield responses to SO_2 were less striking. Both warm-season grasses registered yield decreases ($\bar{x} = 12.8\%$) in the presence of SO_2. Cool-season species were again variable with Dactylis, Phalaris, and Festuca recording $\pm$ 5% decreases in yield and Lolium and Phleum 5-8% increases. None of these differences were statistically significant.

No significant pollutant interactions were noted in this parameter.

Tiller production. Tiller production, important in the filling-in and regeneration of pasture areas, was not greatly affected by the lower levels of oxidant exposure (Table 6). However, the trend was generally towards a negative response and at the highest pollutant load the cool-season species as a group recorded an 8% decrease in tiller number (statistically significant at $p < 0.05$, Table 8). The most striking effect was seen in Phleum where a sharp decline in production of 20% was registered at the highest oxidant level.

SO_2 effects on tiller production were also slight and varied with the species. The greatest effects were seen in Lolium (+ 7.6%) and Phleum (+ 12.3%), with only the former being statistically significant ($p \leq 0.05$).

No statistically significant pollutant interactions were recorded.

GDW per tiller. When gdw per tiller is considered additional biological insight can be gained (Table 7). Thus we see that in Festuca, for example, at high oxidant exposures tiller weight is 14.1 % less ($p < 0.05$). This is also the case in Paspalum. In two other species, Dactylis and Phalaris, tiller weight increased (26%) at high oxidant levels although the actual number remained unchanged or declined. As a group (Table 8), cool-season grasses showed a statistically significant increase in gdw per tiller ($p < 0.05$) although this was clearly at the expense of an equally significant decrease in actual tiller number.

Effects of SO_2 on tiller weight were not large, although the general trend was for tillers to be smaller. This effect was most noticeable in Festuca (- 8.3%) and Paspalum (- 10.1%) although it was statistically significant only in the former ($p < 0.05$).

The main pollutant interaction term was not significant; however, by partitioning the interaction into single df terms a statistically significant ($p < 0.05$) linear relationship, tending to decrease in tiller weight, was indicated in Festuca.

In summary, yield parameters of the forage grass species studied were affected by chronic exposure to O_3 and SO_2. However, the nature of the effect varied according to the species and the parameter considered. Yield responses of the warm-season grasses appeared to be affected detrimentally by such exposures. Among the cool-season grasses effects were much more variable and generalizations are not possible. However, yield of both Phleum and Lolium was clearly negatively affected by high oxidant exposures.

Forage quality

General nutritional parameters: carbohydrate content. Carbohydrate content proved to be seriously affected by oxidant exposure. All species recorded essentially linear decreases in percent total nonstructural carbohydrates (TNC) with increasing pollutant loads (Table 9). When carbohydrate levels in plants at the highest oxidant concentrations were compared with those of plants in the most filtered treatment, reductions in TNC content ranged from 16-56%.

Cool-season grasses seemed to be most sensitive to oxidant exposure (Table 12) with four out of five species registering 50% reductions in percent TNC at the highest level ($\bar{x} = 41.6\%$, $p < 0.01$). Reductions in warm-season grasses were less but still substantial; mean reduction at the highest exposure was 19.4% ($p < 0.01$). Linear regressions and correlations between percent TNC and ozone level were statistically significant in both warm-season ($p < 0.01$) and cool-season species ($p < 0.05$).

SO_2 exposure affected carbohydrate content less dramatically. Cool-season species generally registered a decline in percent TNC ($\bar{x} = 13.6\%$) in the presence of 10 pphm SO_2, with Lolium presenting the exception with a recorded 6.1% increase. Dactylis and Phalaris were the most sensitive cool-season species with declines in TNC of 18.9 and 22.3% ($p < 0.05$), respectively. Warm-season grasses did not appear to be detrimentally affected, registering a slight mean increase in percent TNC (2.6%) in the presence of SO_2.

No interaction of O_3 and SO_2 on carbohydrate content was noted.

Protein content. Protein levels were also affected by oxidant levels with a mean increase in percent crude protein of approximately 10% occurring in most species (Tables 10 and 12) when values at the highest pollutant load were compared with those at the lowest exposure (warm season $\bar{x} = 9.9\%$; cool-season $\bar{x} = 12.5\%$, $p < 0.01$). The two exceptions were Phleum with a 27.2% increase ($p < 0.05$) and Phalaris with a slight loss (2.2%). Analysis of variance revealed that linearity of response was statistically significant ($p < 0.05$) in four species (Lolium, Dactylis, Festuca, and Phleum).

Exposure to 10 pphm SO_2 produced slight to negligible effects on crude protein content, with the most noticeable effects being registered by Phalaris (+ 4.2%) and Festuca (+ 5.6%).

No main interactions on protein levels were recorded by the individual species although a significant linear component was indicated for Dactylis and a significant quadratic component for Paspalum once the interaction was partitioned. However, a statistically significant interactive effect between ozone and SO_2 was indicated from ANOVA when cool-season species were considered as a group ($p < 0.05$), with the relationship being quadratic in nature ($p < 0.01$). A similar quadratic relationship was indicated for the warm-season species ($p < 0.05$); however, the over-all response was not statistically significant.

Digestibility. In the majority of cases, percent crude fiber (CF) was higher at the highest oxidant exposure than at the most filtered level (Table 11). These increases were of the order of 7-9% in Dactylis, Phalaris, and Festuca and were statistically significant ($p < 0.05$) in the case of Festuca. However, significant linear response was indicated for both Festuca ($p < 0.01$) and Dactylis ($p < 0.05$). When considered as a group, a statistically significant increase ($p < 0.05$) in percent crude fiber of 5% was noted for the cool-season grasses (Table 12).

Little or no response of crude fiber content to SO_2 was noted. The largest effect was seen in Phalaris which registered a 3.7% increase in CF level in the presence of 10 pphm SO_2. None of the differences noted proved to be statistically significant nor were any interactive effects detected.

Mineral components: calcium. When considered as a group, calcium content of cool-season grasses showed essentially no response to oxidant exposure ($\bar{x} = 0.06\%$, Table 16). However, when considered individually, effects were noted in two species at the highest exposure level (Table 13). Phleum registered an increase of 13.2% and Phalaris a decrease of 8.3%, although neither effect proved to be statistically significant. A quite different situation exists with the warm-season grasses where a statistically significant increase ($p < 0.01$) of 18% was recorded. Linearity of the response was also significant at $p < 0.01$ (ANOVA).

When the grasses are grouped according to physiological type, SO_2 effects on calcium content appear minor. However, in four out of five cool-season species the trend is for decreased calcium content in the presence of 10 pphm SO_2 and this effect reaches statistical significance ($p < 0.01$) in Lolium. An opposite trend is exhibited by the warm-season species where a mean increase is noted (4.4%) although this is not statistically significant according to ANOVA.

Interactions between SO_2 and O_3 were not evident.

Magnesium. Effects of oxidant exposure on the magnesium levels of cool-season grasses were varied (Table 14), with two species recording increases (Festuca and Phleum), two registering decreases (Dactylis and Phalaris), and the fifth showing essentially no response (Lolium). None of these differences were statistically significant. In contrast, both warm-season species exhibited decided increases in magnesium content at the highest exposure level ($\bar{x} = 25.6\%$). These differences were statistically significant at $p < 0.01$ for the individual species and at $p < 0.001$ when they were grouped. Similar levels of significance were registered when linearity of response was considered (ANOVA). Linear regressions and correlations between percent magnesium and ozone level were statistically significant ($p < 0.05$).

No pattern was evident in the responses of these grasses to SO_2 exposure. In most species levels of magnesium showed little or no change. The greatest changes were registered in Phleum (- 6.5%) and Cynodon (+ 6.7%); however, these did not prove to be statistically significant.

No interaction of pollutants was noted.

Phosphorus. When values at the highest oxidant exposure are compared with those of the most filtered level the over-all trend in these species is toward a slight increase in phosphorus content (Table 15). This trend is strongest in Lolium, Phleum, and Cynodon where 13-14% increases are registered. However, in two species decreased levels are noted, reaching 15.5% in Phalaris. None of these differences proved to be statistically significant either individually or when the species were grouped by physiological type (Table 16).

A similar trend to increased phosphorus levels was also noted upon exposure to SO_2. Both warm-season species exhibited noticeable increases ($\bar{x} = 17.5\%$), as did the cool-season Festuca (7.6%). Differences in these three species did prove to be statistically significant ($p < 0.05$). More modest increases were recorded in the remaining species with Phleum being the only species to register a decrease (4.6%).

No interaction of pollutants was noted on phosphorus content.

To summarize, chronic exposure to O_3 and SO_2 did have significant effects on the quality of the forage grasses studied. This was particularly true in the case of oxidant exposure.

Most dramatic were the carbohydrate data which indicate a rather severe loss of forage quality in the area of energy content under oxidant levels that are found commonly in Southern California. Since the response was essentially linear with oxidant level (rather than of a threshold nature), substantial losses occurred at even intermediate levels in sensitive species. This may have direct relevance in the Northern California region where the three most sensitive species (Lolium, *Dactylis*, and especially, *Phleum*) are regularly grown.

The existence of a similar trend among the cool-season species with SO_2 exposure is also cause for concern.

Noticeable increases in protein levels were recorded in most species with oxidant exposure. On the surface, it might seem that these increases are a beneficial effect. However, it is not accidental that the species registering the highest increase in percent crude protein (*Phleum*) is also the one registering the greatest decrease in percent TNC. On the contrary, this is but the most striking example of the general trend, reflecting the fact that basic source-sink relationships have been disturbed in these species by oxidant exposure. (Much the same might also be said about the increased mineral levels discussed below.)

Crude fiber was significantly increased in cool-season grasses indicating a decrease in digestibility in response to oxidant exposure.

Mineral component levels among the warm-season grasses appeared to be very responsive to pollutant exposure. Highly significant increases in calcium and, especially, magnesium were noted with oxidant exposure while a significant increase in phosphorus was recorded upon SO_2 exposure. Two cool-season grasses also registered significant effects on mineral levels with SO_2 exposure: calcium content was reduced in *Lolium* and phosphorus levels were increased in *Festuca*.

A significant pollutant interaction on protein level was evident when the cool-season grasses were considered as a group. That is, the increase in crude protein level in the presence of both SO_2 and O_3 was greater than additive. Suggestion of a similar trend among the warm-season grasses was also noted.

Grazing simulation study

Before addressing the topic of pollutant-grazing interactions, perhaps it would be best to clarify an important point. The effects discussed in the following paragraphs are based only on end-of-season comparisons. That is, effects of grazing on pollutant responses of these grasses at earlier growth stages will not be considered here. (Such considerations, however, may be very important; Shropshire et al., unpublished data.) Additionally, it should be remembered that this study was conducted with mixed-gas fumigation only, therefore no separation between ozone and SO_2 effects is possible.

It is not within the scope of this report to address in depth the over-all effects of clipping on yield and quality parameters of these forage grasses. However, for the background information required for understanding how pollutants alter the effects of defoliation, a brief summary of clipping responses (as determined by this study) follows:

a. Regular defoliation generally resulted in decreases in gram dry weight yield, gdw per tiller, carbohydrate content, and calcium levels.

b. Clipping increased crude protein content and phosphorus levels in all species.

c. In the remaining parameters (tiller production, crude fiber content, and magnesium levels), responses were species-specific.

Within this context then, the following observations were made:

Yield factors. Statistically significant interactions ($p < 0.05$) of pollutants with clipping occurred in two cool-season species. Gram dry weight yield was reduced in *Lolium* by clipping but reduced significantly further when pollutant stress was present (Table 17). In the same species, the effects on tiller production when pollutants were present was to nullify the decrease in number of tillers caused by defoliation (Table 18). Tillering increased with clipping in *Phleum* in the absence of pollutant stress but decreased when pollutants were present. No significant pollutant-clipping interaction on gdw per tiller was noted (Table 19).

General nutritional parameters. No clipping-pollutant interactions were recorded in these grasses on percent total nonstructural carbohydrate (Table 20), percent crude protein (Table 21), or percent crude fiber (Table 22).

Mineral components. Significant clipping-pollutant interactions on mineral content were registered in two cool-season species. In *Dactylis*, defoliation decreased magnesium content in the absence of pollutants; however, an increase was evident when pollutant stress was added ($p < 0.05$, Table 24). Phosphorus content of *Festuca* was increased by clipping but this effect was reversed when pollutant stress was added ($p < 0.01$, Table 25). No clipping-pollutant interaction was noted in these grasses in terms of calcium content (Table 23).

Thus, while interactions between pollutants and grazing on yield and quality factors are not general throughout these forage grasses, they do occur in some species. Of most concern here would be the decreased yield registered in *Lolium*.

RANGE GRASS SPECIES

Yield factors

GDW yield. In six of the seven species studied, gram dry weight yield at the highest oxidant exposure was reduced over that at the most filtered level (Table 26). When considered as a group (since all of these grasses are cool-season species) the mean decrease was 5.6% (Table 29). However, yield reduction in two species was noticeably greater. *Bromus rubens* registered a biomass decrease of 16.5% and *Festuca megalura* a decrease of 19.9% ($p < 0.05$). The response of the latter species also proved to be significantly linear ($p < 0.05$). Only in *Hordeum leporinum* was an increase in yield (5.3%) registered at the highest oxidant level.

Before proceeding further it might be well to address the problem of population variability in these species. Unlike the cultivated forage grasses which are fairly uniform genetically, the range plants studied here were taken from wild populations retaining a much higher degree of genotypic variability. The high coefficients of variation noted for the responses discussed here are reflective of this fact. Such variability to some degree confounds statistical analysis. Thus, results that may be biologically significant frequently fail to register as statistically significant. This is quite likely the case with several of the factors considered in this study. Therefore, response patterns will regularly be discussed in some length although statistically they were not shown to be significant.

To continue, then, gdw yield responses to SO_2 exposure were variable. In at least three species, however, a slight increase in biomass was recorded in the presence of 10 pphm SO_2. These species were Bromus rubens, B. rigidis, and Hordeum leporinum ($\bar{x}$ = 7.3%). On the other hand, in Festuca megalura and Avena barbata slight decreases in yield were noted (2.7% and 7.3%, respectively). Thus, when the biomass values of these grasses are considered as a group the mean (+ 0.7%) indicates no response of gdw yield to SO_2.

No significant interactions between ozone and SO_2 on biomass were observed.

Tiller production. The effect of oxidant exposure on tiller production in these grasses was small (Table 27). At the highest exposure level, 4-6% increases in tiller number were recorded in four species (Bromus mollis, B. tectorum, Festuca megalura, and Hordeum leporinum) while decreases of 2-5% were registered in two others (B. rubens and B. rigidis). Tiller production in Avena barbata was essentially unchanged. None of these differences were statistically significant.

In most cases, effects of SO_2 exposure on tiller number were essentially negligible ($\pm$ 2%). In Avena barbata and Hordeum leporinum, however, increases of 7.2% and 8.1%, respectively, were noted.

No interaction of pollutants was evident.

GDW per tiller. When the above parameters are integrated in the term gdw per tiller, two trends were apparent (Table 28). In four species, (Avena barbata, Bromus rigidis, B. tectorum, and Hordeum leporinum), there was essentially no change in tiller weight with oxidant exposure. In the three remaining species, on the other hand, noticeable decreases in gdw per tiller were recorded: 10.2% in Bromus mollis, 21.1% in B. rubens, and 25.0% in Festuca megalura. Thus, when all of these grasses are considered as a group a mean reduction in tiller weight of 11.7% is evident (Table 29). According to ANOVA, however, only the weight decrease in Festuca megalura proved significant ($p < 0.01$) and the response was clearly linear ($p < 0.001$). This relationship between O_3 dosage and tiller weight reduction was confirmed by linear regression analysis ($p < 0.001$). In contrast to ANOVA, linear regression analysis also indicated significance ($p < 0.05$) for a similar relationship in Bromus rubens.

In the majority of species, tiller weight responded only slightly ($\pm$ 3%) to SO_2 exposure. The major exception was Bromus rigidis where a 9.5% increase in gdw per tiller was recorded.

No direct interaction of pollutants was noted. However, a statistically significant ($p < 0.05$) linear relationship, tending to decrease in tiller weight, was indicated in Festuca megalura.

In summary, effects of chronic exposure to O_3 and SO_2 at these levels had generally small effects on the yield parameters of these grasses when considered as a group. The major exception was tiller weight where an 11.7% reduction was noted with exposure to high oxidant levels. The implications of this decrease in tiller weight with regard to survivability in the natural environment are worthy of consideration.

When considered individually, however, potentially significant effects are seen in several species. Detrimental effects on yield with oxidant exposure are clearly indicated for Festuca megalura and the same is quite probably true for Bromus rubens and the highly desirable B. mollis. SO_2 exposure, on the other hand, may possibly favor the undesirable B. rigidis.

Forage quality

General nutritional parameters: carbohydrate content. In these species, as in the forage grasses, highly significant decreases in percent total nonstructural carbohydrates were registered with increasing oxidant levels. Even at the relatively low levels studied here (65% lower than those during the forage fumigation), a mean reduction of 11.9% was recorded at the least filtered treatment (Table 33). This effect was statistically significant ($p < 0.01$) and was linear with dose ($p < 0.01$).

When considered individually, sensitivity to the presence of ozone clearly varied with the species (Table 30). In one species (Festuca megalura), an actual increase in TNC of 13% was noted when values at the least filtered treatment were compared with those at the most filtered. In all other species, however, decreases in TNC were recorded in similar comparisons. Least affected was Bromus mollis with a decrease of 4.9%. Hordeum leporinum and Bromus rigidis were more sensitive with decreases of 9-13%. Most sensitive were Bromus rubens, B. tectorum and Avena barbata where decreases in percent TNC at the highest oxidant level reached 18-21%. Statistically, however, only the decrease in Avena barbata (19.9%) was significant ($p < 0.05$).

Effects of SO_2 exposure were slight when the group was considered as a whole ($\bar{x} = 3.9\%$). When considered individually, clearly significant reductions ($p < 0.05$) in TNC were recorded in Bromus rubens (16.1%) and B. tectorum (22.2%). Less marked decreases were also seen in Avena barbata (8.0%) and Bromus mollis (3.4%). In the remaining three species, slight increases in TNC content of the order of 2-6% were recorded in the presence of 10 pphm SO_2.

Statistically significant pollutant interactions on carbohydrate content were noted in Avena barbata ($p < 0.05$). The nature of this interaction, however, proved to be highly complex (cubic term, $p < 0.01$).

Protein content. All species registered increased protein content at the highest oxidant levels, with values ranging from 4.2 - 23.7% (Table 31). The mean increase for the grouped species was 9.2%. The relationship between increased protein content and increased oxidant levels was shown to be linear ($p < 0.05$) but it did not prove to be statistically significant (Table 33). On an individual basis, the least affected species were Hordeum leporinum and Bromis mollis (+ 4-5%). Next in order of response were Bromus rigidis, Festuca megalura, and Bromus tectorum (+ 7-10%). Species most affected were Bromus rubens (+ 15.1%) and Avena barbata

(23.7%). Of the above differences only those in *Bromus mollis*, *B. rubens*, and *Festuca megalura* proved to be statistically significant ($p < 0.05$).

When exposed to 10 pphm SO_2, crude protein levels in these species generally changed very little. In six out of seven species, changes were in the range of $\pm$ 2.5%. *Bromus mollis* provided the exception, with an increase in protein content of 4.3%. None of these differences was statistically significant.

No statistically significant pollutant interactions were noted. However, suggestions of a relationship were seen in *Bromus rubens* and *Festuca megalura* in the cubic term ($p < 0.05$).

Digestibility. When considered as a group, essentially no change is recorded in percent crude fiber with oxidant exposure in these species (Table 33). Individually considered, however, some differences do appear (Table 32). In five of the species, increases in crude fiber percentage occur at the highest oxidant level, generally slight (2-3%) but reaching 8% in *Bromus rubens*. Under similar treatments, a slight decrease in crude fiber is recorded in *Festuca megalura* (2.7%) while *Hordeum leporinum* shows no response. None of these differences was statistically significant.

Responses of crude fiber content to SO_2 exposure were also slight, with most changes being of the order of $\pm$ 2%. *Bromus tectorum* and *B. rubens* were the exceptions, recording increases of 3.3% and 4.2%, respectively. In the case of *Bromus tectorum*, this difference proved to be statistically significant ($p < 0.05$).

Direct interaction of O_3 and SO_2 on crude fiber percentages were indicated for both *Avena barbata* and *Bromus mollis*. The relationship appears to be quadratic for *Avena barbata* ($p < 0.01$) but more complex in *Bromus mollis* (cubic term, $p < 0.01$). There is also a suggestion of a quadratic relationship in *Festuca megalura* ($p < 0.05$).

Mineral components: calcium. The general trend in these species was for calcium content to increase somewhat with oxidant exposure. When considered as a group a mean increase of 7.3% at the highest exposure level was recorded (Table 37). However, values for the individual species varied considerably (Table 34). In three species (*Hordeum leporinum* *Bromus rigidis*, and *B. tectorum*) these increases were in the range of 2 - 4% while in *Avena barbata* a decrease of similar magnitude was registered. More substantial increases in calcium content were recorded in the remaining species: *Festuca megalura*, 12.0%; *Bromus rubens*, 12.2%, and *B. mollis*, 21.3%. None of these differences was judged statistically significant.

When the mean value for calcium content with SO_2 exposure is considered an opposite trend is indicated ($\bar{x} = -5.7\%$). However, this mean is probably skewed in a negative direction through the heavy influence of *Bromus mollis*. In five of the seven species only small changes in calcium content amounting to $\pm$ 3.6% were recorded. Differences were more evident in the two remaining species with *Bromus rubens* registering an increase of 8.8% and the aforementioned *B. mollis* indicating a marked decrease of 23.3%. This latter effect did prove to be statistically significant ($p < 0.05$).

No direct interaction of the polllutants on calcium content was seen. However, suggestions of a relationship of a quadratic nature were noted in Bromus rigidis ($p < 0.05$).

Magnesium. When considered as a group, a mean decrease of 5.6% was recorded for these grasses at the highest oxidant level (Table 37). Values, again, ranged widely for the individual species (Table 35). In Bromus rubens a slight increase (5.4%) was registered while in the six remaining species unchanged or decreased magnesium levels were noted. Decreases were most evident in Bromus tectorum (9.0%), Avena barbata (9.4%), and Festuca megalura (18.9%). None of these effects proved to be of direct statistical significance (ANOVA) although suggestions of a quadratic relationship were seen in Festuca megalura ($p < 0.05$).

No effect of SO_2 exposure on magnesium content was noted when the species were considered as a group ($\bar{x} = -0.6\%$). However, in five of the seven species slight decreases in magnesium levels of less than 6% were recorded. In two species, Bromus tectorum and Avena barbata, slight increases were noted (1.4% and 6.3%, respectively). None of these differences was statistically significant.

No direct interaction of the pollutants was noted although suggestions of a relationship were again seen in Bromus rigidis, this time of a linear nature ($p < 0.05$).

Phosphorus. All species showed increased phosphorus levels at the highest oxidant exposure (Table 36), a fact reflected in the group mean of + 6.5% (Table 37). Relatively minor effects were seen in Bromus mollis (+ 0.8%) and Hordeum leporinum (+ 3.0%). More substantial changes were evident in Bromus tectorum (+ 5.6%), Festuca megalura (+ 7.2%), and Bromus rubens (+ 9.3%). Avena barbata and Bromus rigidis were most responsive with recorded increases of approximately 13%. These effects were of direct statistical significance only in the case of Festuca megalura ($p < 0.05$) where both linear and quadratic components were indicated. However, indications of a linear relationship were seen in both Avena barbata and Bromus rigidis ($p < 0.05$).

In most cases, effects of SO_2 exposure on phosphorus level were minor ($\pm$ 2.6%; $\bar{x} = -0.9\%$). In three species, however, changes were slightly greater: Hordeum leporinum, (- 5.4%); Bromus rubens, (- 5.6%); and Avena barbata, (+ 6.0%). None of these differences was statistically significant.

Interactions of SO_2 and O_3 on phosphorus content were not noted.

In summary, forage quality parameters of the range grasses studied here were sensitive to chronic exposure to both SO_2 and O_3. Oxidant effects were predominant; however, significant effects of SO_2 exposure were also noted in several species.

Most prominent again was the linear decrease in carbohydrate levels with oxidant exposure. This decrease was registered although the fumigation was conducted during the "cleanest" part of the year and used only dilutions of naturally occurring ozone. Thus, a significant loss in this aspect of quality is potentially indicated for natural grasslands in the Southern California region currently and perhaps in many other areas of the state as well.

Significant decreases in carbohydrate content were also noted in at least two species with exposure to 10 pphm SO_2.

Protein levels in these species also increased with oxidant exposure. This effect was again significantly correlated ($p < 0.05$) with the decrease in carbohydrate content.

Crude fiber content was increased significantly with SO_2 exposure in at least one species.

Responses to O_3 and SO_2 fumigation were seen in the mineral components of several species. Statistically significant were the reduction in calcium levels with SO_2 exposure in Bromus mollis and the increased phosphorus content with oxidant treatment in Festuca megalura. However, other noticeable effects on mineral levels were also recorded: increased calcium with oxidant exposure in Bromus mollis, B. rubens, and Festuca megalura; decreased magnesium levels with oxidant exposure in Festuca megalura, and increased phosphorus content with oxidant exposure in Avena barbata and Bromus rigidis.

Indications and suggestions of significant pollutant interactions on quality parameters were much more common in these species than in the forage grasses. Significant interaction was indicated for Avena barbata in TNC and crude fiber and for Bromus mollis in crude fiber. Interactions were also suggested in crude protein of Bromus rubens, calcium and magnesium levels of Bromus rigidis, and protein and crude fiber content of Festuca megalura. This is cause for concern, particularly since these effects were noted at the low pollutant levels of a winter fumigation.

Grazing simulation study

Again, as background for discussion of clipping-pollutant interaction, the following brief summary of defoliation effects in these species (as determined by this study) is provided:

a. In general, regular defoliation resulted in decreases in gram dry weight yield, gdw per tiller, and carbohydrate content.

b. Clipping generally increased levels of crude protein, calcium, magnesium, and phosphorus.

c. Tiller production responses were species-specific.

With this in mind, the following observations were made:

Yield factors. Statistically significant pollutant-clipping interaction occurred in only one case (Tables 38-40). Gram dry weight per tiller in Festuca megalura decreased due to both clipping and pollutant stress singly, but this effect was lessened when both factors were present ($p < 0.05$).

General nutritional factors. No significant interaction of factors was evident in crude protein or crude fiber content (Tables 42 and 43). However, interaction was significant in the case of total nonstructural carbohydrate content in Bromus tectorum (Table 41). Carbohydrate levels decreased in this species due to both clipping and pollutant stress singly. When both factors were present, the reduction in carbohydrate content was greater than additive ($p < 0.01$).

Mineral components. A significant pollutant-clipping interaction on mineral content was exhibited by only one species (Tables 44-46). Bromus tectorum decreased in magnesium content due to pollutant stress. This effect was ameliorated, however, when defoliation stress was also imposed ($p < 0.01$).

In summary, interaction between pollutants and simulated grazing on yield and quality parameters did occur in some species. In one case this interaction proved to be detrimental while in the others it appeared to be essentially advantageous.

DISCUSSION

From the results presented above, it should be clear that the presence of these air pollutants did modify both yield and quality responses in many of our California range and forage grasses. In particular, oxidant exposure at the levels studied here (all ambient or less) affected all species considered.

Oxidant effects. In terms of yield, both biomass and tiller production were affected. In the majority of species gram dry weight yield decreased with oxidant exposure. This trend agrees well with the findings of Price & Treshow (1972), Youngner & Nudge (1980), and Flagler & Youngner (1980). Yield decreases in Lolium perenne with chronic ozone exposure have also been reported by Horsman et al (1980). However, in one range species and three cool-season forage grasses apparent increases in yield were registered. Such yield increases in Dactylis glomerata are in direct contrast to the observations of Horsman et al (1980). These workers also recorded yield decreases in Phalaris aquatica while increased yield was noted here in the related Phalaris arundinacea. As previously mentioned, since no assessment of visual injury was made, it is impossible to establish whether the increases noted here represent truly beneficial effects of ozone exposure or whether they merely indicate regrowth after damage. There is some indirect evidence for the latter possibility in the fact that forage protein quality clearly decreased in the species involved (see below).

Tiller production decreased in most cool-season forage grasses with oxidant exposure. Similar trends were seen previously in Festuca and Lolium by Youngner and Nudge (1980). In contrast, increases were registered in the warm-season Paspalum and in several range species. However, when gram dry weight per tiller is considered it is clear that tiller weight is decreasing in most of these latter species, often markedly. Neither response, whether decreased rate of tiller production or decreased tiller weight (and, therefore, presumably survival), is likely to be beneficial to the establishment and long-term maintenance of grassland cover.

Turning to oxidant effects on forage quality, highly detrimental linear effects on carbohydrate content were registered in the cultivated forage grasses, especially in the cool-season species. A similar trend, equally significant but of lesser degree, was noted in the range species. (It should be reiterated that the less marked responses of the range species should not be taken to mean that they are less susceptible than the forage species. Oxidant dosage during the winter range grass fumigation was approximately 3510 pphm-hr in contrast to the summer forage grass dosage of 10,750 pphm-hr. Under equivalent oxidant levels, there is every reason to expect that degree of response in these cool-season annuals would be very similar to that of the forage species.) These reductions in total nonstructural carbohydrates with chronic ozone exposure concur with previous observations in citrus (Dugger et al, 1966; Dugger & Palmer, 1969) and with the recent report of Flagler and Youngner (1980) in *Festuca*.

Increased crude protein content was observed with ozone exposure in all but one of the grass species studied. This finding agreed with several previous reports (Bennett, 1969; Tingey et al, 1973; Tingey & Neeley in Tingey, 1974) in non-grass species and with data on *Festuca* presented by Flagler and Youngner (1980). When expressed on a yield basis (percent crude protein/gdw yield), these increases are maintained in all but four species. In these four species, which are the same four species recording increased gdw yield with oxidant exposure, protein content per gram dry weight remained essentially unchanged (*Dactylis*, *Festuca*) or decreased noticeably (*Phalaris*, *Hordeum leporinum*). These data on *Festuca* contrast with the findings of Flagler and Youngner (1980) who noted a significant decrease.

A tendency for crude fiber content to increase slightly with oxidant exposure, thereby decreasing digestibility, was indicated for most species. This trend was statistically significant in the cool-season forage grasses and was correlated with both carbohydrate decrease ($p < 0.01$) and protein increase ($p < 0.05$). These findings are in contrast to the reports of Thompson et al (1976) in alfalfa, Flagler (1980) in *Festuca*, and Ben-Ghedalia & Miron (1981) in wheat straw.

Oxidant exposure clearly affected mineral levels in the warm-season forage grasses. Both calcium and magnesium content were significantly elevated with exposure at ambient ozone levels. These increases in magnesium level were correlated ($p < 0.05$) with decreased carbohydrate content. The cool-season range species also tended to show a slight increase in calcium with exposure but this trend was not statistically significant. A tendency for increased phosphorus levels was seen in all range species and in the warm-season forage grasses when grouped. In the latter case, this increase in phosphorus level was highly correlated ($p < 0.01$) with both decreased gdw yield and increased protein content.

From the above findings it can be concluded that oxidant exposure at the ambient levels studied here results in detrimental effects on both yield and quality of forage and range grasses. Although ozone exposure increased the levels of several quality factors it would be very shortsighted, indeed, to consider any such increase as beneficial without understanding how this factor fits into the overall biological framework of the plant. For example, the recorded increases in crude protein levels are quite possibly an indirect result of a significant disruption in the vital carbon-fixing machinery of the plant. When seen in this context, the majority of the component increases noted here would appear to be dependent upon concomitant decreases in the levels of other components. Thus, the increases in protein and minerals are quite likely occurring at the expense of carbohydrate level (energy content) and yield.

The net result of these changes would seem to be a potentially serious decline in the livestock carrying capacity of California's pastures and rangelands with exposure to oxidants at the levels currently experienced in the Riverside area. Even in the absence of livestock, these effects are matters of concern in that such changes could be affecting the survival and growth of the grassland cover so important in erosion control.

Sulfur dioxide effects. Effects of chronic SO_2 fumigation on these grasses were much less than those of O_3. However, both the SO_2 treatment level and the dosage were also much less than in the case of ozone exposure. This was particularly true of the forage grass fumigation where total ozone dosage at the highest treatment level was 10,750 pphm-hr with at least 200 pphm-hr above 15 pphm. Mean SO_2 dosage for the same period was 3071 pphm-hr at a set level of 10 pphm. Levels were more equivalent during the range grass fumigation where recorded ozone exposure levels did not exceed 10 pphm. However, ozone dosage at the highest treatment levels was 3510 pphm-hr while SO_2 dosage was 2220 pphm-hr. Thus, it would not be accurate to assume that the fewer effects noted with SO_2 fumigation indicate a less toxic nature of the pollutant.

The most prominent effect of SO_2 exposure on yield was seen in the warm-season forage grasses where a noticeable decrease in gdw yield was recorded. Responses of the cool-season grasses, both forage and range, were more variable with at least five species registering increases in gdw with SO_2 exposure. Such increases have at times been reported in the literature. Ferenbaugh (1978), for instance, reported increased yield of the desert grass Oryzopsis hymenoides at low SO_2 levels. To some degree, the report of Davis et al (1966) was supported in that the majority of the range species (5 of 7) showed no detrimental biomass effects with SO_2 exposure. However, the slightly increased yields of Lolium perenne and Phleum pratense with SO_2 fumigation contrast with the reports of English workers (e.g., Bell & Clough, 1973; Lockyer et al, 1976; Horsman et al, 1979; Ashenden & Williams, 1980). Among the species registering slight decreases in yield with SO_2 exposure was Festuca arundinacea, an observation in agreement with recent data of Flagler (1980).

In tiller production, the general trend was that no detrimental effects occurred with SO_2 exposure. This was particularly true of the range species. Three cool-season species (two forage, one range) registered noticeable increases in tiller number with fumigation. Among these was Lolium perenne, in which the recorded increase was statistically significant, a finding in contrast to previous reports by Bell & Clough (1963) and Cowling & Koziol (1978). The observation of an increase in tillering in Phleum pratense also differs with previous work (Ashenden & Williams, 1980).

The picture becomes a bit complex when gdw per tiller is considered. However, in most range grasses tiller weight was relatively unaffected by SO_2 exposure, the exception being one species which registered a noticeable increase. Forage grasses were more variable with four species recording slight to moderate decreases in tiller weight with fumigation. In *Festuca arundinacea* this decrease proved to be statistically significant, an observation not in agreement with Flagler (1980) who indicated no effect.

Detrimental SO_2 effects on yield parameters were thus generally slight with the warm-season grasses presenting perhaps the major exception.

In terms of quality parameters, several significant SO_2 effects were noted. Noticeable decreases in carbohydrate content were registered in most cool-season forage species. [The decrease in *Festuca arundinacea*, however, differs from the observation of Flagler (1980)]. Similar reductions were also noted in four range species. Although mean reductions with SO_2 were not of the same order of magnitude as mean ozone-induced decreases, in the three species where these effects were statistically significant the SO_2-induced decreases were essentially equal to or greater than those caused by ozone. In contrast, no detrimental effects on carbohydrate content were noted in the warm-season species. These data would tend to support the suggestion by Winner and Mooney (1980) that the process of carbon fixation in cool-season (or C_3) species is more sensitive to SO_2 stress than that of warm-season (or C_4) species.

In most grasses, crude protein levels showed a slight tendency to rise with SO_2 fumigation. This was true of warm-season grasses as well as cool-season species. However, a close correlation between increased protein and decreased carbohydrate was not apparent with SO_2 exposure. Similar tendencies for increased protein levels with SO_2 fumigation are evident in the work of Davis et al (1966) (although they were disregarded) and in Flagler (1980) working with *Festuca arundinacea*.

Crude fiber levels in these species were generally unaffected by SO_2 exposure. However, in three cool-season grasses (one forage, two range) slight increases were registered, one of which was statistically significant. The lack of effect noted here in *Festuca arundinacea* is in agreement with Flagler (1980).

SO_2 fumigation often affected mineral levels in these species. Large, statistically significant increases in phosphorus were recorded in both warm-season grasses. A similar tendency was also noticed in most cool-season forage species and one range species. Statistically significant decreases in calcium content were noted in two cool-season species (one forage, one range) with SO_2 exposure. In the case of the range species the effect was quite marked. Several other cool-season species also showed similar trends. Warm-season species, on the other hand, tended to slightly increased calcium levels. Magnesium content was generally little affected by SO_2 fumigation, although there may be a slight trend to decreased levels in the range species. These findings are essentially contrary to trends discussed by Faller (1970-71). Differing observations on phosphorus responses were also reported by Pandey & Rao (1978) in wheat and by Flagler & Youngner (1980) in *Festuca arundinacea*.

Assessing the over-all effect of SO_2 fumigation on these species is difficult. Although detrimental effects are noted, they are generally species-specific.

In terms of yield parameters, at least as many beneficial effects were noted as detrimental effects among cool-season species. However, both warm-season grasses did indicate decreased gdw yield with SO_2 exposure.

Among quality factors, carbohydrate levels did tend to decline (often markedly) in the cool-season species although there were several exceptions. Phosphorus levels were clearly elevated in warm-season species while a tendency toward decreased calcium content was observed in many cool-season species.

Perhaps the greatest cause for concern at this point would be the marked decrease in carbohydrate levels (energy content) among several of the cool-season species. The three forage grasses showing such effects are quite often grown in Northern California. Similar decreases in carbohydrate content are also seen in two of the most common range species. Therefore, the potential does exist for SO_2-induced forage quality losses in this important aspect.

A second area of concern would be the decreased gdw yields seen in both warm-season species with exposure to SO_2.

Ozone-sulfur dioxide effects. Significant ozone-sulfur dioxide interactions were recorded in two species and suggestions of interaction were noted in quite a few more. Such interactions generally involved quality parameters although there were suggestions in two species that tiller weight responses might be affected.

There is also some suggestion that interactions were more common among the annual range grasses. However, it would be difficult to support such a generalization at this time since environmental conditions during the two fumigations were so different. In particular, the pollutant dosage ratio at the highest treatment level was approximately 3.5 O_3 : 1 SO_2 in the forage grass study, which was conducted during the heavily-polluted summer season. During the winter range grass study, in contrast, the pollutant dosage ratio was much closer: 1.6 O_3 : 1 SO_2. The effect of such differences in pollutant ratios is currently an active topic of study and quite likely alters plant responses.

Grazing. Statistically significant clipping-pollutant interaction was registered in six cool-season grasses (four forage, two range). Both quality and yield factors were involved in such interactions.

Very little more can be said at this time. Since mixed gases were used in this fumigation no separation of pollutant effects can be made. It is quite possible that ozone may cause more severe effects with clipping in the absence of SO_2. Sulfur dioxide may be ameliorating some defoliation effects. Obviously, this area needs more study.

Compositional effects.

Implicit in the differential range grass susceptibilities noted above is the possibility of compositional changes occurring in our natural grasslands with chronic exposure to air pollutants. The nature of these changes, however, would be strongly dependent upon the type and level of the pollutant(s) and the management practices involved (i.e., grazing frequency).

Such changes may be favorable or unfavorable. In order to address this latter point, we must first indicate which species are considered desirable and which are not and in which context (forage or erosion control). For the purposes of this discussion, the following ratings based on forage evaluations will be used:

Very desirable:	Bromus mollis
Intermediate:	Avena barbata, Bromus rubens, B. tectorum, Festuca megalura, Hordeum leporinum
Very undesirable:	Bromus rigidis

Oxidant effects. With oxidant levels equivalent to the ambient winter levels in Riverside, gram dry weight yield and tiller weight decreases in Bromus rubens and Festuca megalura suggest that these intermediate species might decline in representation. Carbohydrate losses in Avena barbata and Bromus tectorum indicate that these two species may also be unfavored. The very desirable Bromus mollis appeared to be relatively tolerant of oxidant exposure as did Hordeum leporinum and the very undesirable Bromus rigidis. (Since seed of Bromus rubens and Hordeum leporinum was collected from the UCR campus some possibility exists that pre-selection for ozone tolerance may have occurred in these species. If that is the case, then even greater ozone-induced decreases in gram dry weight yield and tiller weight might be expected in Bromus rubens populations from less polluted areas.)

Other factors being constant, the net result of these changes would tend to be increased representation of both the most and least desirable species at the expense of several species of intermediate value.

Sulfur dioxide effects. With exposure to 10 pphm SO_2, slightly beneficial effects on yield were noted in at least two species, Hordeum leporinum and Bromus rigidis. Bromus rubens also registered slight increases in yield; however, significant decreases in carbohydrate suggest exposure may ultimately prove unfavorable. Gdw yield in Bromus mollis, B. tectorum, and Festuca megalura appeared to be relatively unaffeacted at this SO_2 level although significant carbohydrate loss in B. tectorum again is suggestive of eventual vulnerability. Decreased yield was most evident in Avena barbata.

The over-all pattern which emerges with SO_2 fumigation is somewhat similar to that with ozone in that the major detrimental effects are seen in the species of intermediate value. The very desirable Bromus mollis again appears to be relatively unaffected and could be expected to persist. However, suggestions of beneficial effects on the undesirable Bromus rigidis are quite unwelcome.

Ozone-sulfur dioxide effects. When both pollutants are present, the possibility of unfavorable effects on Avena barbata is somewhat ameliorated. Specifically, loss in carbohydrate content is significantly less than would be expected from the results of exposure to each pollutant singly.

Grazing effects. Considering only the question of pollutant-grazing interaction, the nature of the interactions observed would tend to indicate some adverse effect on Bromus tectorum.

The above observations regarding potential compositional changes in our natural grasslands with chronic air pollution were made in the context of a hypothetical grassland where all species were equally represented and responding similarly to all other environmental influences. In fact, this is not the case in the real world.

The potential for these pollutant-induced compositional changes varies greatly with geographical location and the susceptibility of the individual species to other environmental factors. The level of concern regarding such changes also varies accordingly.

To take two examples:

1. Decline in Bromus rubens numbers with oxidant exposure may not be of great concern in Northern California where the relatively tolerant and highly desirable Bromus mollis predominates. However, in Southern California where Bromus rubens is the dominant range grass, a decline in representation could be much more serious. This latter case quite possibly reflects the current situation in large areas of the Southern California air basins.

2. Both the highly desirable Bromus mollis and the highly undesirable B. rigidis appear to be relatively tolerant of pollutants in the unclipped state. Both species are also unfavorably affected by clipping. From these facts alone one might go on to predict that B. rigidis may tend toward decreased representation under natural conditions. In fact, the opposite is more likely since B. rigidis is seldom grazed in nature for reasons implicit in its common name (ripgut grass) while B. mollis is likely to be over-grazed.

Thus, the results of this study regarding differential species susceptibilities to air pollutants must be considered within the complete ecological context of the grassland if they are to be put to accurate predictive use.

Table 5. Basic biomass and quality study: analysis of variation in gram dry weight yield of above ground portions in 7 forage grass species.

A. Means.

Combination	Count per mean	B	O	S	LOL	DAC	PHL	PHA	FES	PAS	CYN
B	8	1	0	0	21.53	23.19	19.18	31.62	37.23	100.21	85.42
		2	0	0	22.93	22.45	19.28	26.59	33.06	77.79	81.05
O - 100%	4	0	1	0	22.98 yz	21.62	20.07	26.75	33.75 yz	102.44	90.27
67%		0	2	0	21.04 z	22.75	20.59	30.56	37.99 x	83.27	86.89
33%		0	3	0	24.56 y	21.60	20.19	25.19	32.20 z	83.78	83.24
0%		0	4	0	20.35 z	25.30	16.07	33.94	36.64 xy	86.52	72.53
S - 0 pphm	8	0	0	1	21.30	23.56	18.70	29.89	36.08	95.65	86.98
10 pphm		0	0	2	23.17	22.08	19.75	28.32	34.21	82.35	79.48
O x S	2	0	1	1	22.63	20.84	19.70	29.28	32.67	103.65	98.18
		0	2	1	20.13	23.88	19.77	30.85	39.70	96.02	90.57
		0	3	1	22.69	22.60	17.87	25.06	32.23	84.69	84.48
		0	4	1	19.76	26.93	17.48	34.39	39.73	98.26	74.70
		0	1	2	23.35	22.41	20.44	24.22	34.84	101.22	82.36
		0	2	2	21.95	21.63	21.41	30.26	36.28	70.51	83.20
		0	3	2	26.44	20.60	22.50	25.32	32.18	82.87	82.00
		0	4	2	20.94	23.67	14.66	33.48	33.55	74.78	70.37

Table 5: (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	7.854	2.154	0.042	101.100	69.390**	2009.100	76.260
0	3	14.620*	12.110	17.960	61.810	27.870*	329.100	236.500
0_L	1	8.124	23.730	32.750*	76.870	6.881	476.200	659.000*
0_Q	1	5.169	6.454	21.010	24.200	0.058	488.600	49.740
0_C	1	30.580*	6.148	0.133	84.350	76.680**	22.440	0.658
S	1	13.930	8.806	4.410	9.938	14.030	708.500	225.100
0xS	3	1.780	4.456	9.413	5.653	13.540	167.600	34.820
0_LxS	1	0.294	11.050	4.693	8.808	29.300*	139.100	72.910
0_QxS	1	3.413	1.719	17.400	8.144	0.059	0.477	27.620
0_CxS	1	1.633	0.602	6.150	0.007	11.260	363.200	3.933
Error	7	2.787	6.667	5.817	18.500	4.832	462.000	89.820
C.V. (%)		7.5	11.3	12.5	14.8	6.3	24.2	11.4

* = Significance at .05
** = Significance at .01

Table 6. Basic biomass and quality study: analysis of variation in number of tillers produced in 7 forage grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	O	S	LOL	DAC	PHL	PHA	FES	PAS	CYN
B	8	1	0	0	121.98	58.80	64.93	65.70	46.83	43.45	N/A
		2	0	0	133.23	60.63	61.58	59.18	49.23	42.75	
O - 100%	4	0	1	0	125.35 yz	61.65	66.60	64.40	50.05	41.10 z	
67%		0	2	0	131.85 yz	60.60	66.90	61.95	47.80	41.35 z	
33%		0	3	0	136.15 y	59.60	67.70	59.00	47.00	48.40 y	
0%		0	4	0	117.05 z	57.00	51.80	64.40	47.25	41.55 z	
S - 0 pphm	8	0	0	1	122.93	61.13	59.58	62.68	47.08	44.10	
10 pphm		0	0	2	132.28	58.30	66.93	62.20	48.98	42.10	
O x S	2	0	1	1	122.20	59.40	59.40	65.90	49.40	40.10	
		0	2	1	132.00	59.20	60.80	61.50	48.80	45.70	
		0	3	1	126.50	67.60	66.20	58.10	43.90	47.90	
		0	4	1	111.00	58.30	51.90	65.20	46.20	42.70	
		0	1	2	128.50	63.90	73.80	62.90	50.70	42.10	
		0	2	2	131.70	62.00	73.00	62.40	46.80	37.00	
		0	3	2	145.80	51.60	69.20	59.90	50.10	48.90	
		0	4	2	123.10	55.70	51.70	63.60	48.30	40.40	

Table 6. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	506.200**	13.320	44.890	170.300*	23.040	1.960	N/A
0	3	276.700*	15.880	233.900	26.340	7.737	50.070*	
0_L	1	116.500	45.390	424.200	0.399	16.550	5.096	
0_Q	1	652.700**	2.817	256.700	62.200	6.478	51.750*	
0_C	1	60.970	0.076	20.860	16.430	0.179	93.370*	
S	1	349.700*	31.920	216.100	0.902	14.440	16.000	
0xS	3	69.660	86.310	49.720	4.902	11.370	23.330	
0_LxS	1	41.050	50.980	127.400	1.094	2.385	3.184	
0_QxS	1	0.212	59.480	0.123	13.430	0.209	13.440	
0_CxS	1	167.700	148.500	21.590	0.187	31.510	53.360	
Error	7	40.410	34.530	171.900	16.900	14.310	7.954	
C.V. (%)		5.0	9.8	20.7	6.6	7.9	6.5	

* = Significance at .05
** = Significance at .01

Table 7. Basic biomass and quality study: analysis of variation in gram dry weight per tiller in 7 forage grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	O	S	LOL	DAC	PHL	PHA	FES	PAS	CYN
B	8	1	0	0	0.177	0.398	0.304	0.479	0.796	2.31	N/A
		2	0	0	0.172	0.372	0.312	0.449	0.676	1.83	
O - 100%	4	0	1	0	0.183	0.351	0.308	0.415 z	0.683 z	2.49	
67%		0	2	0	0.160	0.378	0.316	0.493 yz	0.792 y	2.00	
33%		0	3	0	0.181	0.367	0.297	0.426 z	0.689 z	1.73	
0%		0	4	0	0.175	0.445	0.312	0.523 y	0.779 y	2.05	
S - 0 pphm	8	0	0	1	0.174	0.389	0.317	0.473	0.768	2.18	
10 pphm		0	0	2	0.175	0.381	0.299	0.455	0.704	1.96	
O x S	2	0	1	1	0.185	0.351	0.332	0.444	0.664	2.60	
		0	2	1	0.152	0.407	0.325	0.500	0.811	2.09	
		0	3	1	0.180	0.334	0.269	0.429	0.735	1.77	
		0	4	1	0.178	0.466	0.340	0.520	0.863	2.26	
		0	1	2	0.182	0.351	0.284	0.387	0.702	2.38	
		0	2	2	0.167	0.349	0.307	0.485	0.774	1.91	
		0	3	2	0.181	0.399	0.325	0.423	0.644	1.70	
		0	4	2	0.171	0.424	0.283	0.526	0.695	1.85	

Table 7. (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	0.089	2.768	0.287	3.501	57.240**	932.900	N/A
0	3	0.456	6.853	0.261	10.820*	13.320*	395.300	
0_L	1	0.048	16.600*	0.000	17.980*	11.760	432.200	
0_Q	1	0.322	2.565	0.047	0.375	0.408	685.200	
0_C	1	0.998*	1.395	0.736	14.110*	27.780*	68.630	
S	1	0.006	0.281	1.195	1.329	16.660*	190.500	
0xS	3	0.085	3.027	2.610	0.751	7.606	19.780	
0_LxS	1	0.016	0.220	0.003	2.023	22.660*	15.540	
0_QxS	1	0.157	0.603	5.136	0.228	0.001	33.040	
0_CxS	1	0.081	8.260	2.692	0.001	0.160	10.770	
Error	7	0.168	1.681	1.684	2.357	2.423	189.800	
C.V. (%)		7.4	10.6	13.3	10.5	6.7	21.1	

* = Significance at .05
** = Significance at .01

[1]Mean squares have been multiplied by 1000 for presentation.

Table 8: Basic biomass and quality study summary: analysis of variation in yield parameters of cool-season (5) and warm-season (2) forage grasses.

A. Means.

Combination	Count per Mean	Subclass			GDW Yield		Tiller Number		GDW/Tiller	
		B	O	S	Cool	Warm	Cool	Warm	Cool	Warm
B	8	1	0	0	26.61	91.56	71.65	N/A	0.373	N/A
		2	0	0	24.88	79.42	72.76		0.342	
O - 100%	4	0	1	0	25.04	96.36	73.60 y		0.341 z	
67%		0	2	0	26.58	85.08	73.83 y		0.361 yz	
33%		0	3	0	24.87	81.01	73.88 y		0.337 z	
0%		0	4	0	26.49	79.53	67.53 z		0.393 y	
S - 0 pphm	8	0	0	1	25.92	91.32	70.69		0.368	
10 pphm		0	0	2	25.57	79.66	73.73		0.347	
O x S	2	0	1	1	25.03	100.92	71.25		0.352	
		0	2	1	26.87	93.36	72.50		0.371	
		0	3	1	24.09	84.59	72.45		0.333	
		0	4	1	27.72	86.49	66.55		0.417	
		0	1	2	25.05	91.79	75.95		0.330	
		0	2	2	26.30	76.86	75.15		0.350	
		0	3	2	25.66	77.44	75.30		0.341	
		0	4	2	25.26	72.58	68.50		0.369	

Table 8: (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	GDW Yield		Tiller Number		GDW/Tiller[1]	
		Cool	Warm	Cool	Warm	Cool	Warm
B	1	11.990*	589.400	4.951	N/A	3.783*	N/A
0	3	3.359	231.700	39.020*		2.641*	
0_L	1	2.582	591.600	72.610*		4.531*	
0_Q	1	0.006	101.200	42.230		1.309	
0_C	1	7.487	2.395	2.210		2.084	
S	1	0.515	543.700	36.910		1.695	
0xS	3	2.782	18.230	1.377		0.524	
0_LxS	1	2.234	4.855	3.556		0.218	
0_QxS	1	2.959	0.062	0.349		0.821	
0_CxS	1	3.154	49.780	0.227		0.533	
Error	7	1.683	202.100	8.399		0.450	
C.V. (%)		5.0	16.6	4.0		5.9	

* = Significance at .05

[1]Mean squares have been multiplied by 1000 for presentation.

Table 9. Basic biomass and quality study: analysis of variation in percentage total nonstructural carbohydrate content in 7 forage grass species.

A. Means.

Combination	Count per Mean	B	O	S	LOL	DAC	PHL	PHA	FES	PAS	CYN
B	8	1	0	0	7.42	6.85	5.18	13.97	7.39	7.48	25.39
		2	0	0	7.44	7.91	6.64	13.04	7.91	6.90	25.62
O - 100%	4	0	1	0	9.18 y	9.29 y	9.14	15.63	10.59 y	8.84 y	27.44 y
67%		0	2	0	7.16 yz	7.78 yz	4.98	12.00	8.10 yz	7.40 yz	25.52 y
33%		0	3	0	8.93 y	7.78 yz	5.54	13.61	6.38 z	6.18 z	26.15 y
0%		0	4	0	4.45 z	4.66 z	3.99	12.78	5.55 z	6.34 z	22.90 z
S - 0 pphm	8	0	0	1	7.21	8.15	6.35	15.19	8.07	6.90	25.38
10 pphm		0	0	2	7.65	6.61	5.47	11.81	7.24	7.48	25.63
O x S	2	0	1	1	9.18	11.58	10.23	11.03	11.17	8.95	27.16
		0	2	1	6.07	9.09	5.24	12.62	8.46	6.28	26.01
		0	3	1	9.19	7.84	5.75	15.84	6.59	6.18	25.58
		0	4	1	4.40	4.09	4.20	14.29	6.07	6.18	22.79
		0	1	2	9.19	7.00	8.05	13.24	10.02	8.74	22.73
		0	2	2	8.25	6.48	4.72	11.38	7.73	8.52	25.03
		0	3	2	8.67	7.73	5.34	11.37	6.17	6.18	26.73
		0	4	2	4.51	5.24	3.78	11.27	5.03	6.50	23.01

Table 9. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	0.002	4.569	8.483	3.497	1.082	1.375	0.221
0	3	18.990**	15.140*	20.160	9.789	19.850**	6.031**	14.610**
0_L	1	38.300**	41.790*	49.160*	12.700	55.150***	14.180***	38.320**
0_Q	1	5.808	2.415	7.102	7.955	3.045	2.720*	1.640
0_C	1	12.880*	1.224	4.230	8.713	1.342	1.189	3.881
S	1	0.788	9.440	3.124	45.700*	2.789	1.375	0.235
0xS	3	1.423	6.548	0.755	2.617	0.108	1.262	0.813
0_LxS	1	0.070	18.380	1.530	0.687	0.012	0.007	0.000
0_QxS	1	0.579	0.172	0.713	1.073	0.273	1.116	0.089
0_CxS	1	3.618	1.096	0.022	6.090	0.040	2.663	2.349
Error	7	1.406	3.472	5.906	4.979	1.365	0.355	1.337
C.V. (%)		16.0	25.3	41.1	16.5	15.3	8.3	4.5

* = Significance at .05
** = Significance at .01
*** = Significance at .001

Table 10. Basic biomass and quality study: analysis of variation in percentage crude protein content in 7 forage grass species.

A. Means.

Combination	Count per Mean	Subclass B	Subclass O	Subclass S	LOL	DAC	PHL	PHA	FES	PAS	CYN
B	8	1	0	0	9.94	9.00	10.65	6.64	6.90	3.36	3.16
		2	0	0	9.50	8.72	9.97	6.45	6.88	4.01	3.65
0 - 100%	4	0	1	0	9.24	8.50	9.15 z	6.46	6.33 z	3.39	3.26
67%		0	2	0	9.78	8.92	10.34 yz	6.71	6.90 yz	3.93	3.45
33%		0	3	0	9.54	8.77	10.12 z	6.68	7.17 y	3.71	3.31
0%		0	4	0	10.32	9.25	11.64 y	6.32	7.17 y	3.72	3.59
S - 0 pphm	8	0	0	1	9.77	8.77	10.34	6.41	6.70	3.62	3.39
10 pphm		0	0	2	9.67	8.95	10.28	6.68	7.08	3.75	3.42
0 x S	2	0	1	1	9.39	8.09	8.70	5.95	5.97	3.05	3.12
		0	2	1	10.47	8.77	10.75	6.76	6.92	4.22	3.43
		0	3	1	9.42	8.74	10.47	6.53	7.13	3.84	3.42
		0	4	1	9.79	9.49	11.43	6.39	6.80	3.38	3.59
		0	1	2	9.09	8.91	9.60	6.97	6.69	3.73	3.40
		0	2	2	9.09	9.07	9.93	6.65	6.88	3.65	3.47
		0	3	2	9.67	8.81	9.77	6.83	7.21	3.58	3.21
		0	4	2	10.86	9.02	11.85	6.25	7.55	4.06	3.59

Table 10. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	0.783	0.305	1.863	0.141	0.002	1.716*	0.956**
0	3	0.841	0.396	4.211*	0.135	0.635*	0.202	0.089
0_L	1	2.124*	1.034*	11.720**	0.043	1.531*	0.162	0.185
0_Q	1	0.053	0.003	0.094	0.363	0.344	0.282	0.007
0_C	1	0.346	0.150	0.816	0.000	0.029	0.161	0.076
S	1	0.034	0.128	0.011	0.286	0.574	0.070	0.003
0xS	3	1.055	0.290	0.712	0.292	0.172	0.420	0.041
0_LxS	1	1.333	0.870*	0.091	0.570	0.002	0.002	0.051
0_QxS	1	0.876	0.000	2.023	0.122	0.506	1.206*	0.053
0_CxS	1	0.956	0.000	0.022	0.184	0.007	0.052	0.019
Error	7	0.250	0.151	0.663	0.184	0.129	0.176	0.047
C.V. (%)		5.1	4.4	7.9	6.6	5.2	11.4	6.3

* = Significance at .05
** = Significance at .01

Table 11. Basic biomass and quality study: analysis of variation in percentage crude fiber content in 7 forage grass species.

A. Means.

Combination	Count per Mean	B	O	S	LOL	DAC	PHL	PHA	FES	PAS	CYN
B	8	1	0	0	26.17	26.28	25.51	24.01	25.52	33.99	20.83
		2	0	0	26.04	25.73	24.71	24.88	25.42	33.75	20.84
O - 100%	4	0	1	0	25.84	24.96	24.39	23.44	24.41 z	33.21	21.08
67%		0	2	0	26.53	26.27	26.04	25.23	25.83 y	33.72	20.89
33%		0	3	0	25.81	25.56	25.10	23.98	25.46 yz	34.35	20.81
0%		0	4	0	26.24	27.22	24.91	25.13	26.17 y	34.21	20.57
S - 0 pphm	8	0	0	1	26.27	25.78	25.14	24.00	25.45	34.21	20.89
10 pphm		0	0	2	25.94	26.23	25.08	24.89	25.48	33.53	20.79
O x S	2	0	1	1	26.05	23.60	23.58	22.90	24.15	32.90	20.91
		0	2	1	26.68	26.80	26.16	24.66	25.95	34.78	21.09
		0	3	1	25.89	25.49	25.86	23.42	25.28	34.71	20.99
		0	4	1	26.45	27.24	24.96	25.02	26.44	34.45	20.56
		0	1	2	25.63	26.33	25.21	23.99	24.68	33.53	21.26
		0	2	2	26.38	25.74	25.92	25.80	25.72	32.66	20.69
		0	3	2	25.73	25.64	24.33	24.54	25.64	33.98	20.64
		0	4	2	26.03	27.21	24.87	25.24	25.89	33.98	20.59

Table 11. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	0.065	1.227	2.528	2.984	0.039	0.240	0.001
0	3	0.471	3.790	1.898	3.076	2.310*	1.068	0.176
0_L	1	0.143	8.907*	0.227	4.171	5.493*	2.368	0.527
0_Q	1	0.066	0.111	3.347	0.413	0.533	0.436	0.002
0_C	1	1.205*	2.353	2.120	4.642*	0.906	0.399	0.000
S	1	0.423	0.797	0.013	3.195	0.003	1.809	0.037
0xS	3	0.015	2.601	1.683	0.202	0.255	1.279	0.046
0_LxS	1	0.000	3.102	1.787	0.381	0.459	0.339	0.125
0_QxS	1	0.035	3.284	2.802	0.218	0.006	2.259	0.324
0_CxS	1	0.010	1.418	0.461	0.008	0.300	1.238	0.006
Error	7	0.190	1.450	1.507	0.747	0.448	0.583	0.252
C.V. (%)		1.7	4.6	4.9	3.5	2.6	2.3	2.4

* = Significance at .05
** = Significance at .01

Table 12. Basic biomass and quality study summary: analysis of variation in general nutritional factors of cool-season (5) and warm-season (2) forage grasses.

A. Means.

Combination	Count per Mean	Subclass			Percentage					
					TNC		C.P.		C.F.	
		B	O	S	Cool	Warm	Cool	Warm	Cool	Warm
B	8	1	0	0	8.16	16.44	8.63	3.26	25.50	27.42
		2	0	0	8.61	16.26	8.30	3.83	25.36	27.30
O - 100%	4	0	1	0	10.77 Y	18.15 Y	7.94 Y	3.33	24.61 z	27.15
67%		0	2	0	8.00 YZ	16.46 YZ	8.53 Y	3.70	25.98 y	27.31
33%		0	3	0	8.50 YZ	16.17 Z	8.46 Y	3.51	25.18 yz	27.58
0%		0	4	0	6.29 Z	14.62 Z	8.94 Z	3.66	25.93 y	27.40
S - 0 pphm	8	0	0	1	9.00	16.14	8.40	3.51	25.33	27.55
10 pphm		0	0	2	7.78	16.56	8.53	3.59	25.52	27.17
O x S	2	0	1	1	12.04	18.06	7.62	3.09	24.06	26.91
		0	2	1	8.30	16.15	8.73	3.83	26.05	27.94
		0	3	1	9.04	15.88	8.47	3.63	25.19	27.86
		0	4	1	6.61	14.49	8.78	3.49	26.02	27.51
		0	1	2	9.50	18.23	8.25	3.57	25.17	27.40
		0	2	2	7.71	16.78	8.32	3.56	25.91	26.68
		0	3	2	7.96	16.46	8.46	3.39	25.18	27.31
		0	4	2	5.97	14.76	9.10	3.83	25.85	27.29

Table 12. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Percentage					
		TNC		C. P.		C. F.	
		Cool	Warm	Cool	Warm	Cool	Warm
B	1	0.815	0.126	0.419*	1.311**	0.078	0.054
0	3	13.630**	8.348**	0.680**	0.112	1.716*	0.130
0_L	1	37.370***	24.810***	1.915***	0.170	2.687*	0.164
0_Q	1	0.363	0.034	0.015	0.049	0.393	0.122
0_C	1	3.158	0.196	0.110	0.115	2.069*	0.106
S	1	5.893	0.681	0.069	0.026	0.156	0.589
0xS	3	8.314	0.049	0.200*	0.153	0.375	0.528
0_LxS	1	1.567	0.003	0.026	0.008	0.757	0.158
0_QxS	1	0.587	0.141	0.472**	0.450*	0.305	1.076
0_CxS	1	0.340	0.002	0.101	0.002	0.062	0.350
Error	7	1.187	0.566	0.038	0.060	0.316	0.211
C.V. (%)		13.0	4.6	2.3	6.9	2.2	1.7

* = Significance at .05
** = Significance at .01
*** = Significance at .001

Table 13. Basic biomass and quality study: analysis of variation in percentage calcium content in 7 forage grass species.

A. Means.

Combination	Count per Mean	Subclass B	Subclass O	Subclass S	LOL	DAC	PHL	PHA	FES	PAS	CYN
B	8	1	0	0	0.684	0.359	0.377	0.698	0.489	0.397	0.439
		2	0	0	0.676	0.354	0.317	0.632	0.506	0.552	0.391
0 - 100%	4	0	1	0	0.662	0.357	0.341	0.699	0.509	0.437	0.396 z
67%		0	2	0	0.692	0.367	0.352	0.668	0.482	0.477	0.412 yz
33%		0	3	0	0.684	0.354	0.307	0.651	0.499	0.468	0.379 z
0%		0	4	0	0.682	0.350	0.386	0.641	0.498	0.517	0.471 y
S - 0 pphm	8	0	0	1	0.692	0.362	0.368	0.668	0.487	0.470	0.401
0 pphm		0	0	2	0.668	0.351	0.325	0.662	0.508	0.479	0.429
0 x S	2	0	1	1	0.673	0.370	0.349	0.720	0.510	0.409	0.399
		0	2	1	0.712	0.358	0.384	0.697	0.458	0.483	0.368
		0	3	1	0.703	0.360	0.338	0.623	0.485	0.468	0.365
		0	4	1	0.680	0.360	0.401	0.629	0.493	0.519	0.470
		0	1	2	0.650	0.344	0.333	0.678	0.508	0.465	0.394
		0	2	2	0.671	0.375	0.319	0.638	0.506	0.470	0.456
		0	3	2	0.664	0.347	0.276	0.679	0.513	0.467	0.393
		0	4	2	0.684	0.339	0.371	0.652	0.503	0.514	0.471

Table 13. (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	0.210	0.105	14.280*	17.290*	1.225	96.410***	9.216**
0	3	0.654	0.206	4.211	2.642	0.489	4.298	6.352**
0_L	1	0.692	0.179	2.772	7.341	0.114	11.810	9.335**
0_Q	1	1.002*	0.169	4.622	0.504	0.672	0.074	5.696*
0_C	1	0.267	0.271	5.240	0.081	0.683	1.005	4.024
S	1	2.450**	0.473	7.396	0.132	1.764	0.380	3.080
0xS	3	0.432	0.358	0.595	2.938	0.466	0.996	1.786
0_LxS	1	0.375	0.001	0.080	3.459	0.027	1.657	0.014
0_QxS	1	0.919	0.605	1.686	0.083	1.118	1.076	3.499
0_CxS	1	0.003	0.468	0.017	5.272	0.253	0.256	1.845
Error	7	0.179	0.839	1.529	2.296	1.629	2.329	0.733
C.V. (%)		2.0	8.1	11.3	7.2	8.1	10.2	6.5

* = Significance at .05
** = Significance at .01
*** = Significance at .001

[1]Mean squares have been multiplied by 1000 for presentation.

Table 14. Basic biomass and quality study: analysis of variation in percentage magnesium content in 7 forage grass species.

A. Means.

Combination	Count per Mean	B	O	S	LOL	DAC	PHL	PHA	FES	PAS	CYN
B	8	1	0	0	0.380	0.559	0.186	0.336	0.613	0.147	0.149
		2	0	0	0.360	0.560	0.228	0.314	0.591	0.157	0.130
O - 100%	4	0	1	0	0.372	0.593	0.202	0.339	0.599	0.139 z	0.127 z
67%		0	2	0	0.371	0.548	0.220	0.324	0.601	0.151 yz	0.144 yz
33%		0	3	0	0.363	0.557	0.184	0.320	0.580	0.148 z	0.124 z
0%		0	4	0	0.374	0.541	0.220	0.318	0.628	0.170 y	0.163 y
S - 0 pphm	8	0	0	1	0.377	0.557	0.214	0.321	0.599	0.154	0.135
10 pphm		0	0	2	0.363	0.562	0.200	0.329	0.604	0.150	0.144
O x S	2	0	1	1	0.381	0.618	0.212	0.329	0.624	0.137	0.130
		0	2	1	0.383	0.505	0.215	0.333	0.590	0.156	0.132
		0	3	1	0.354	0.559	0.196	0.313	0.582	0.150	0.121
		0	4	1	0.390	0.544	0.231	0.309	0.601	0.173	0.156
		0	1	2	0.362	0.567	0.193	0.349	0.574	0.140	0.124
		0	2	2	0.258	0.591	0.226	0.315	0.611	0.145	0.155
		0	3	2	0.372	0.554	0.172	0.326	0.578	0.146	0.126
		0	4	2	0.359	0.537	0.209	0.327	0.654	0.167	0.171

Table 14. (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	1.743	0.009	7.225*	1.914	2.048	0.400*	1.369*
0	3	0.098	2.122	1.170	0.373	1.529	0.696**	1.312**
0_L	1	0.004	4.914	0.252	0.934	1.266	1.882**	2.113**
0_Q	1	0.152	0.844	0.314	0.184	2.083	0.083	0.519
0_C	1	0.137	0.607	2.945	0.001	1.238	0.122	1.304*
S	1	0.798	0.132	0.729	0.248	0.105	0.081	0.342
0xS	3	0.485	3.329	0.271	0.318	1.897	0.037	0.148
0_LxS	1	0.014	0.328	0.042	0.009	4.779	0.037	0.146
0_QxS	1	0.460	4.787	0.189	0.465	0.053	0.036	0.081
0_CxS	1	0.981	4.872	0.582	0.481	0.858	0.038	0.217
Error	7	0.720	1.444	0.547	0.416	1.857	0.070	0.132
C.V. (%)		7.2	6.8	11.3	6.3	7.2	5.5	8.2

* = Significance at .05
** = Significance at .01

[1]Mean squares have been multiplied by 1000 for presentation.

Table 15. Basic biomass and quality study: analysis of variation in percentage phosphorus content in 7 forage grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	O	S	LOL	DAC	PHL	PHA	FES	PAS	CYN
B	8	1	0	0	0.321	0.274	0.264	0.290	0.211	0.113	0.130
		2	0	0	0.343	0.316	0.242	0.254	0.227	0.142	0.162
O - 100%	4	0	1	0	0.309	0.286	0.238	0.290	0.211	0.125	0.131
67%		0	2	0	0.343	0.297	0.248	0.279	0.217	0.132	0.158
33%		0	3	0	0.320	0.309	0.256	0.273	0.229	0.131	0.144
0%		0	4	0	0.355	0.289	0.270	0.245	0.219	0.121	0.150
S - 0 pphm	8	0	0	1	0.328	0.290	0.259	0.263	0.211	0.119	0.132
10 pphm		0	0	2	0.336	0.301	0.247	0.280	0.227	0.136	0.159
O x S	2	0	1	1	0.300	0.270	0.232	0.290	0.201	0.115	0.115
		0	2	1	0.350	0.290	0.256	0.266	0.202	0.124	0.137
		0	3	1	0.310	0.312	0.269	0.259	0.229	0.124	0.138
		0	4	1	0.350	0.287	0.278	0.237	0.213	0.111	0.139
		0	1	2	0.319	0.301	0.243	0.289	0.221	0.136	0.147
		0	2	2	0.337	0.303	0.240	0.291	0.232	0.139	0.178
		0	3	2	0.329	0.306	0.243	0.287	0.229	0.137	0.150
		0	4	2	0.360	0.292	0.261	0.252	0.224	0.130	0.160

Table 15. (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	1.871	6.972*	1.849	5.256	1.139*	3.306**	4.128**
0	3	1.788	0.422	0.729	1.467	0.226	0.107	0.487
0_L	1	3.407*	0.057	2.168	4.122	0.175	0.050	0.482
0_Q	1	0.002	0.942	0.009	0.268	0.272	0.270	0.433
0_C	1	1.954	0.267	0.012	0.009	0.229	0.000	0.547
S	1	0.315	0.462	0.600	1.089	0.946*	1.156*	2.836*
0xS	3	0.232	0.237	0.261	0.165	0.162	0.016	0.149
0_LxS	1	0.005	0.406	0.421	0.128	0.111	0.002	0.114
0_QxS	1	0.123	0.218	0.351	0.366	0.000	0.043	0.000
0_CxS	1	0.567	0.086	0.012	0.000	0.374	0.002	0.333
Error	7	0.563	0.765	0.551	1.533	0.115	0.143	0.318
C.V. (%)		7.1	9.4	9.3	14.4	4.9	9.4	12.2

* = Significance at .05
** = Significance at .01

[1]Mean squares have been multiplied by 1000 for presentation.

Table 16. Basic biomass and quality study summary: analysis of variation in mineral components of cool-season (5) and warm season (2) forage grasses.

A. Means.

Combination	Count per Mean	Subclass			Ca		Mg		P	
		B	O	S	Cool	Warm	Cool	Warm	Cool	Warm
B	8	1	0	0	0.521	0.418	0.415	0.148	0.255	0.122
		2	0	0	0.497	0.472	0.411	0.144	0.266	0.152
O - 100%	4	0	1	0	0.514	0.417 Z	0.421	0.133 Z	0.243	0.129
67%		0	2	0	0.512	0.445 YZ	0.413	0.147 Z	0.277	0.145
33%		0	3	0	0.499	0.424 Z	0.401	0.136 Z	0.257	0.138
0%		0	4	0	0.511	0.494 Y	0.416	0.167 Y	0.266	0.136
S - 0 pphm	8	0	0	1	0.516	0.435	0.414	0.145	0.265	0.126
10 pphm		0	0	2	0.503	0.454	0.412	0.147	0.256	0.148
O x S	2	0	1	1	0.525	0.404	0.433	0.133	0.259	0.115
		0	2	1	0.522	0.426	0.405	0.144	0.273	0.131
		0	3	1	0.502	0.417	0.401	0.136	0.275	0.131
		0	4	1	0.513	0.495	0.415	0.165	0.253	0.125
		0	1	2	0.503	0.430	0.409	0.132	0.227	0.142
		0	2	2	0.502	0.463	0.420	0.150	0.280	0.159
		0	3	2	0.496	0.430	0.400	0.137	0.239	0.144
		0	4	2	0.510	0.493	0.417	0.169	0.278	0.146

Percentage applies to Ca, Mg and P columns.

Table 16. (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

Source	df	Percentage					
		Ca		Mg		P	
		Cool	Warm	Cool	Warm	Cool	Warm
B	1	2.352	11.610**	0.072	0.077	0.506	3.721**
0	3	0.182	4.882**	0.299	0.951***	0.813	0.184
0_L	1	0.042	10.610**	0.087	2.046***	0.711	0.060
0_Q	1	0.201	1.767	0.562	0.255*	0.627	0.342
0_C	1	0.303	2.268	0.248	0.552**	1.103	0.151
S	1	0.676	1.425	0.016	0.028	0.306	1.892*
0xS	3	0.093	0.281	0.263	0.010	0.907	0.048
0_LxS	1	0.223	0.493	0.246	0.010	1.219	0.035
0_QxS	1	0.001	0.167	0.345	0.003	0.119	0.013
0_CxS	1	0.056	0.182	0.197	0.017	1.382	0.094
Error	7	0.319	0.523	0.331	0.035	0.302	0.180
C.V. (%)		3.5	5.1	4.4	4.0	6.7	9.8

* = Significance at .05
** = Significance at .01
*** = Significance at .001

[1]Mean squares have been multiplied by 1000 for presentation.

Table 17. Grazing simulation study: analysis of variation in gram dry weight yield in 7 forage grass species.

A. Means.

Combination	Count per Mean	Subclass B	Subclass P	Subclass C	Species LOL	DAC	PHL	PHA	FES	PAS	CYN
B	4	1	0	0	20.19	19.59	15.97	23.85	26.97	76.40	70.34
		2	0	0	22.58	18.50	18.25	22.74	27.81	64.96	68.56
P –	4	0	1	0	21.15	19.08	16.79	25.17	28.05	79.85	76.19
+		0	2	0	21.61	19.01	17.43	20.92	26.73	61.51	62.72
C –	4	0	0	1	24.53	20.72	21.10	27.30	31.67	88.26	90.09
+		0	0	2	18.23	17.37	13.12	18.78	23.11	53.10	48.81
P x C	2	0	1	1	22.63	20.84	16.70	29.28	32.67	103.65	98.18
		0	2	1	26.44	20.60	22.50	25.32	30.68	72.87	82.00
		0	1	2	19.67	17.33	13.89	21.05	23.44	56.06	54.19
		0	2	2	16.79	17.41	12.36	16.52	22.78	50.14	43.43

Table 17. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	11.450*	2.376	10.350	0.744	1.437	261.400	6.372
P	1	0.428	0.011	0.819	36.120	3.525	673.300	362.900
C	1	79.440**	22.450	127.200**	145.000*	146.800**	2472.800	3408.100*
P x C	1	22.340*	0.051	9.374	0.162	0.891	309.100	14.690
Error	3	1.089	5.980	2.396	10.900	1.201	609.100	188.000
C.V. (%)		4.9	12.8	9.0	14.3	4.0	34.900	19.7

* = Significance at .05
** = Significance at .01

Table 18. Grazing simulation study: analysis of variation in number of tillers produced in 7 forage grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	P	C	LOL	DAC	PHL	PHA	FES	PAS	CYN
B	4	1	0	0	135.90	58.95	56.65	95.70	49.80	59.50	N/A
		2	0	0	141.55	60.30	71.25	95.75	56.20	61.80	
P –	4	0	1	0	134.55	61.35	63.75	101.45	53.35	61.85	
+		0	2	0	142.90	57.90	64.15	90.00	52.65	59.45	
C –	4	0	0	1	184.00	55.50	64.30	62.90	49.75	44.50	
+		0	0	2	143.45	63.75	63.60	128.55	56.25	76.80	
P x C	2	0	1	1	122.20	59.40	59.40	65.90	49.40	40.10	
		0	2	1	145.80	51.60	69.20	59.90	50.10	48.90	
		0	1	2	146.90	63.30	68.10	137.00	57.30	83.60	
		0	2	2	140.00	64.20	59.10	120.10	55.20	70.00	

Table 18. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	63.840	3.645	426.300*	0.005	81.920	10.580	N/A
P	1	139.400	23.810	0.320	262.200	0.980	11.520	
C	1	178.600	136.100	0.980	8619.800*	84.500	2086.600**	
P x C	1	465.100*	37.840	176.700*	59.410	3.920	25.090	
Error	3	36.860	15.650	13.320	344.200	17.110	42.410	
C.V. (%)		4.4	6.6	5.7	19.4	7.8	10.7	

* = Significance at .05
** = Significance at .01

Table 19. Grazing simulation study: analysis of variation in gram dry weight per tiller in 7 forage grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	P	C	LOL	DAC	PHL	PHA	FES	PAS	CYN
B	4	1	0	0	0.150	0.334	0.280	0.293	0.547	1.54	N/A
		2	0	0	0.160	0.313	0.258	0.287	0.504	1.19	
P –	4	0	1	0	0.160	0.312	0.270	0.299	0.539	1.63	
+		0	2	0	0.150	0.335	0.268	0.281	0.513	1.10	
C –	4	0	0	1	0.183	0.375	0.328	0.433	0.638	2.04	
+		0	0	2	0.127	0.272	0.210	0.147	0.413	0.69	
P x C	2	0	1	1	0.185	0.351	0.332	0.444	0.664	2.60	
		0	2	1	0.181	0.399	0.325	0.423	0.613	1.49	
		0	1	2	0.134	0.273	0.208	0.155	0.414	0.67	
		0	2	2	0.120	0.271	0.211	0.138	0.413	0.72	

Table 19: (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	0.171	0.898	1.031	0.071	3.826	239.200	N/A
P	1	0.165	1.117	0.012	0.696	1.348	565.100	
C	1	6.308***	21.130	28.080**	164.600**	101.400**	3632.200	
P x C	1	0.048	1.263	0.052	0.012	1.241	662.500	
Error	3	0.022	0.961	0.450	2.161	1.060	361.700	
C.V. (%)		3.0	9.6	7.9	16.0	6.2	44.0	

* = Significance at .05
** = Significance at .01
*** = Significance at .001

[1]Mean squares have been multiplied by 1000 for presentation.

Table 20. Grazing simulation study: analysis of variation in percentage total nonstructural carbohydrate content in 7 forage grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	P	C	LOL	DAC	PHL	PHA	FES	PAS	CYN
B	4	1	0	0	8.04	8.88	6.27	10.48	6.59	6.06	22.51
		2	0	0	8.57	9.24	6.85	9.65	8.87	5.80	23.31
P –	4	0	1	0	8.82	9.50	8.15	11.94	9.55	6.76	23.20
+		0	2	0	7.78	8.62	4.97	8.19	5.91	5.10	22.61
C –	4	0	0	1	8.93	10.96	7.78	14.70	8.67	7.56	26.94
+		0	0	2	7.68	7.16	5.34	5.43	6.79	4.30	18.87
P x C	2	0	1	1	9.19	11.58	10.23	18.03	11.17	8.95	27.16
		0	2	1	8.67	10.35	5.34	11.37	6.17	6.18	26.73
		0	1	2	8.46	7.42	6.07	5.85	7.94	4.57	19.35
		0	2	2	6.90	6.90	4.61	5.02	5.65	4.03	18.49

Table 20. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	0.551	0.263	0.661	1.386	10.440	0.140	1.288
P	1	2.163	1.540	20.160*	28.010	26.500*	5.478*	0.702
C	1	3.100	28.920**	11.960	171.800*	7.031	21.320**	130.300***
P x C	1	0.541	0.256	5.917	16.970	3.672	2.486	0.056
Error	3	0.441	0.604	1.862	6.008	1.288	0.301	0.780
C.V. (%)		8.0	8.6	20.8	24.4	14.7	9.3	3.9

* = Significance at .05
** = Significance at .01
*** = Significance at .001

Table 21. Grazing simulation study: analysis of variation in percentage crude protein content in 7 forage grass species.

A. Means.

Combination		Count per Mean	Subclass			Species						
			B	P	C	LOL	DAC	PHL	PHA	FES	PAS	CYN
B		4	1	0	0	9.49	8.54	10.23	8.36	7.75	4.31	4.17
			2	0	0	9.70	9.18	9.90	8.33	7.69	4.48	4.46
P	-	4	0	1	0	9.52	8.61	9.52	8.13	7.28	4.19	4.10
	+		0	2	0	9.67	9.11	10.61	8.56	8.16	4.61	4.53
C	-	4	0	0	1	9.53	8.45	9.23	6.39	6.59	3.31	3.16
	+		0	0	2	9.66	9.28	10.90	10.30	8.85	5.46	5.46
P x C		2	0	1	1	9.39	8.09	8.70	5.95	5.97	3.05	3.12
			0	2	1	9.67	8.81	9.77	6.83	7.21	3.58	3.21
			0	1	2	9.65	9.14	10.35	10.31	8.60	5.33	5.08
			0	2	2	9.68	9.42	11.45	10.30	9.11	5.64	5.85

Table 21. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	0.086	0.819	0.224	0.001	0.006	0.061	0.162
P	1	0.050	0.500	2.354	0.370	1.531*	0.353	0.370
C	1	0.038	1.378*	5.544	30.650**	10.220**	9.418***	10.580***
P x C	1	0.030	0.097	0.001	0.396	0.266	0.024	0.238
Error	3	0.210	0.130	0.235	0.428	0.083	0.048	0.042
C.V. (%)		4.8	4.1	4.8	7.8	3.7	5.0	4.8

* = Significance at .05
** = Significance at .01
*** = Significance at .001

Table 22. Grazing simulation study: analysis of variation in percentage crude fiber content 7 forage grass species.

A. Means.

Combination	Count per Mean	Subclass B	Subclass P	Subclass C	Species LOL	DAC	PHL	PHA	FES	PAS	CYN
B	4	1	0	0	26.11	25.10	23.78	24.11	25.78	33.53	21.90
		2	0	0	25.73	24.05	23.41	25.14	24.38	33.88	22.17
P –	4	0	1	0	26.00	24.09	23.73	24.19	24.54	33.49	22.32
+		0	2	0	25.83	25.06	23.46	25.06	25.62	33.93	21.74
C –	4	0	0	1	25.89	24.62	23.95	23.72	24.90	33.44	20.77
+		0	0	2	25.95	24.54	23.24	25.54	25.26	33.97	23.29
P x C	2	0	1	1	26.05	23.60	23.58	22.90	24.15	32.90	20.91
		0	2	1	25.73	25.64	24.33	24.54	25.64	33.98	20.64
		0	1	2	25.96	24.59	23.89	25.49	24.94	34.08	23.74
		0	2	2	25.94	24.48	22.59	25.58	25.59	33.87	22.85

Table 22. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	0.281	2.226	0.285	2.112	3.962	0.245	0.143
P	1	0.058	1.862	0.148	1.505	2.301	0.387	0.679
C	1	0.006	0.013	1.030	6.607	0.270	0.572	12.730*
P x C	1	0.045	2.311	2.112	1.209	0.349	0.832	0.195
Error	3	0.107	0.986	2.387	0.828	0.549	0.477	0.431
C.V. (%)		1.3	4.0	6.5	3.7	3.0	2.0	3.0

* = Significance at .05

Table 23. Grazing simulation study: analysis of variation in percentage calcium content in 7 forage grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	P	C	LOL	DAC	PHL	PHA	FES	PAS	CYN
B	4	1	0	0	0.555	0.383	0.373	0.617	0.454	0.345	0.385
		2	0	0	0.534	0.383	0.315	0.572	0.423	0.393	0.336
P −	4	0	1	0	0.543	0.382	0.369	0.607	0.439	0.361	0.354
+		0	2	0	0.546	0.383	0.319	0.582	0.438	0.377	0.367
C −	4	0	0	1	0.669	0.358	0.313	0.700	0.511	0.438	0.396
+		0	0	2	0.421	0.407	0.376	0.490	0.366	0.300	0.326
P x C	2	0	1	1	0.673	0.370	0.349	0.720	0.510	0.409	0.399
		0	2	1	0.664	0.347	0.276	0.679	0.513	0.468	0.393
		0	1	2	0.413	0.394	0.389	0.494	0.369	0.312	0.310
		0	2	2	0.428	0.420	0.362	0.485	0.364	0.287	0.342

Table 23. (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	0.882	0.000	6.728	4.050	1.922	4.753	4.851
P	1	0.018	0.003	5.000	1.250	0.002	0.561	0.325
C	1	123.000***	4.753	7.938	88.200*	42.050**	38.230*	9.870
P x C	1	0.288	1.176	1.013	0.545	0.032	3.486	0.703
Error	3	0.417	1.087	1.144	3.796	0.345	2.689	1.559
C.V. (%)		3.7	8.6	9.8	10.4	4.2	14.0	10.9

* = Significance at .05
** = Significance at .01
*** = Significance at .001

[1]Mean squares have been multiplied by 1000 for presentation.

Table 24. Grazing simulation study: analysis of variation in percentage magnesium content in 7 forage grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	P	C	LOL	DAC	PHL	PHA	FES	PAS	CYN
B	4	1	0	0	0.301	0.545	0.222	0.373	0.580	0.177	0.182
		2	0	0	0.301	0.573	0.246	0.337	0.548	0.188	0.155
P –	4	0	1	0	0.306	0.557	0.231	0.348	0.585	0.181	0.164
+		0	2	0	0.297	0.562	0.237	0.362	0.544	0.185	0.173
C –	4	0	0	1	0.376	0.586	0.192	0.328	0.601	0.142	0.128
+		0	0	2	0.226	0.532	0.276	0.383	0.528	0.224	0.210
P x C	2	0	1	1	0.381	0.618	0.212	0.329	0.624	0.137	0.130
		0	2	1	0.372	0.554	0.172	0.326	0.578	0.146	0.126
		0	1	2	0.230	0.495	0.250	0.367	0.546	0.224	0.199
		0	2	2	0.222	0.569	0.301	0.398	0.509	0.223	0.220

Table 24: (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	0.000	1.625	1.225	2.521	2.048	0.253	1.458
P	1	0.153	0.050	0.066	0.365	3.445	0.036	0.162
C	1	45.150**	5.725	14.030*	6.050	10.800*	13.530**	13.280**
P x C	1	0.000	9.522*	4.095	0.578	0.032	0.055	0.313
Error	3	0.545	0.612	0.577	0.382	1.047	0.139	0.195
C.V. (%)		7.7	4.4	10.3	5.5	5.7	6.4	8.3

* = Significance at .05
** = Significance at .01

[1]Mean squares have been multiplied by 1000 for presentation.

Table 25. Grazing simulation study: analysis of variation in percentage phosphorus content in 7 forage grass species.

A. Means.

Combination		Count per Mean	Subclass			Species						
			B	P	C	LOL	DAC	PHL	PHA	FES	PAS	CYN
B		4	1	0	0	0.321	0.311	0.368	0.359	0.255	0.129	0.172
			2	0	0	0.367	0.330	0.263	0.338	0.263	0.147	0.178
P	-	4	0	1	0	0.331	0.312	0.281	0.345	0.257	0.130	0.161
	+		0	2	0	0.358	0.329	0.350	0.352	0.260	0.146	0.189
C	-	4	0	0	1	0.315	0.288	0.238	0.289	0.215	0.126	0.133
	+		0	0	2	0.374	0.352	0.393	0.409	0.302	0.150	0.217
P x C		2	0	1	1	0.300	0.270	0.232	0.290	0.201	0.115	0.115
			0	2	1	0.329	0.306	0.243	0.287	0.229	0.137	0.150
			0	1	2	0.362	0.353	0.329	0.400	0.313	0.145	0.207
			0	2	2	0.386	0.351	0.458	0.418	0.291	0.155	0.227

Table 25. (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

Source	df	Species						
		LOL	DAC	PHL	PHA	FES	PAS	CYN
B	1	4.186	0.703	22.160	0.861	0.128	0.648	0.055
P	1	1.431	0.595	9.730	0.105	0.018	0.512	1.485
C	1	7.021*	8.128	48.520	28.920*	15.140***	1.152	14.200**
P x C	1	0.015	0.703	7.021	0.231	1.301**	0.072	0.120
Error	3	0.457	0.829	11.890	2.766	0.017	0.289	0.292
C.V. (%)		6.2	9.0	34.5	15.1	1.6	12.3	9.8

* = Significance at .05
** = Significance at .01
*** = Significance at .001

[1]Mean squares have been multiplied by 1000 for presentation.

Table 26. Basic biomass and quality study: analysis of variation in gram dry weight yield of above ground portions in 7 range grass species.

A. Means.

Combination	Count per Mean	Subclass B	Subclass O	Subclass S	Species AB	BM	BR	BRI	BT	FM	HL
B	8	1	0	0	39.68	13.03	26.93	20.00	10.57	10.81	22.32
		2	0	0	43.63	11.84	25.38	21.16	9.72	10.77	21.15
0 - 100%	4	0	1	0	41.69	12.41	27.83	20.50	10.27	12.20 y	20.96
67%		0	2	0	39.93	13.42	27.06	21.70	9.73	11.91 y	21.95
33%		0	3	0	44.45	12.05	26.49	19.92	10.89	9.29 z	21.95
0%		0	4	0	40.54	11.87	23.24	20.22	9.70	9.77 z	22.08
S - 0 pphm	8	0	0	1	43.23	12.46	25.53	19.63	10.15	10.94	20.97
10 pphm		0	0	2	40.08	12.41	26.78	21.54	10.15	10.64	22.50
0 x S	2	0	1	1	44.40	13.02	31.30	21.40	10.84	13.26	22.27
		0	2	1	40.67	14.30	25.53	21.43	9.72	11.68	20.09
		0	3	1	47.86	11.41	22.82	17.46	11.22	8.87	20.21
		0	4	1	39.99	11.12	22.49	18.23	8.81	9.96	21.33
		0	1	2	38.98	11.79	24.37	19.60	9.71	11.14	19.65
		0	2	2	39.20	12.54	28.59	21.97	9.73	12.13	23.80
		0	3	2	41.05	12.68	30.17	22.39	10.56	9.71	23.70
		0	4	2	41.09	12.63	23.98	22.20	10.59	9.58	22.84

Table 26. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		AB	BM	BR	BRI	BT	FM	HL
B	1	62.530	5.700	9.610	5.394	2.924	0.009	5.429
0	3	16.060	1.906	16.360	2.432	1.256	8.706*	1.087
0_L	1	0.279	1.178	43.150	0.699	0.274	16.060*	2.424
0_Q	1	4.861	1.342	5.831	0.768	0.419	0.707	0.764
0_C	1	43.030	3.199	0.088	5.828	3.075	9.350*	0.072
S	1	39.660	0.012	6.175	14.610	0.000	0.363	9.303
0xS	3	13.120	2.826	35.790	9.664	1.633	1.721	8.598
0_LxS	1	15.320	5.179	39.680	20.540	3.826	1.528	7.864
0_QxS	1	3.861	0.120	63.990	2.946	0.404	3.632	17.470
0_CxS	1	20.190	3.178	3.688	5.501	0.669	0.003	0.464
Error	7	59.120	3.483	14.130	3.894	1.240	1.493	7.481
C.V. (%)		18.5	15.0	14.4	9.6	11.0	11.3	12.6

* = Significance at .05

Table 27. Basic biomass and quality study: analysis of variation in number of tillers produced in 7 range grass species.

A. Means.

Combination	Count per Mean	Subclass B	Subclass O	Subclass S	Species AB	BM	BR	BRI	BT	FM	HL
B	8	1	0	0	30.83	52.38	60.31	37.13	73.78	225.40	49.43
		2	0	0	31.83	50.40	58.43	39.10	77.38	222.33	50.33
0 - 100%	4	0	1	0	30.90	50.40	56.35	38.55	74.45	218.30	49.20
67%		0	2	0	31.95	53.45	61.40	39.70	76.50	233.80	48.50
33%		0	3	0	31.65	47.45	60.38	36.60	81.05	211.35	50.50
0%		0	4	0	30.80	54.25	59.35	37.60	70.30	232.00	51.30
S - 0 pphm	8	0	0	1	32.00	51.48	58.75	37.98	74.95	225.45	47.93
10 pphm		0	0	2	30.65	51.30	59.99	38.25	76.20	222.28	51.83
0 x S	2	0	1	1	33.60	51.30	58.80	39.80	76.00	220.30	48.30
		0	2	1	30.70	55.40	59.65	40.90	76.00	234.00	46.50
		0	3	1	33.00	45.80	57.75	35.50	81.90	201.80	49.50
		0	4	1	30.70	53.40	58.80	35.70	65.90	245.70	47.40
		0	1	2	28.20	49.50	53.90	37.30	72.90	216.30	50.10
		0	2	2	33.20	51.50	63.15	38.50	77.00	233.60	50.50
		0	3	2	30.30	49.10	63.00	37.70	80.20	220.90	51.50
		0	4	2	30.90	55.10	59.90	39.50	74.70	218.30	55.20

Table 27. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		AB	BM	BR	BRI	BT	FM	HL
B	1	4.000	15.600	14.250	15.600	51.840	37.820	3.240
0	3	1.270	38.570	19.000	7.016	79.700	469.900	6.357
0_L	1	0.054	15.620	14.970	4.305	23.190	188.100	11.730
0_Q	1	3.590	14.260	37.200	0.010	163.900	27.670	2.097
0_C	1	0.166	85.820	4.837	16.730	52.560	1194.200	5.241
S	1	7.290	0.123	6.126	0.302	6.250	40.320	60.840
0xS	3	11.820	10.700	19.640	10.330	28.230	363.800	7.747
0_LxS	1	10.540	10.960	18.710	24.530	63.960	201.800	15.660
0_QxS	1	6.261	0.033	39.980	0.464	9.871	626.200	3.149
0_CxS	1	18.650	21.110	0.208	5.992	10.860	263.400	4.433
Error	7	12.710	18.200	43.170	8.637	33.490	424.900	23.260
C.V. (%)		11.4	8.3	11.1	7.7	7.7	9.2	9.7

Table 28. Basic biomass and quality study: analysis of variation in gram dry weight per tiller in 7 range grass species.

A. Means.

Combination	Count per Mean	Subclass			Species							
		B	O	S	AB	BM	BR	BRI	BT	FM		HL
B	8	1	0	0	1.30	0.249	0.448	0.540	0.143	0.048		0.453
		2	0	0	1.37	0.235	0.435	0.541	0.125	0.048		0.420
O - 100%	4	0	1	0	1.37	0.244	0.494	0.533	0.138	0.056	X	0.426
67%		0	2	0	1.26	0.252	0.443	0.546	0.127	0.051	XY	0.452
33%		0	3	0	1.39	0.253	0.439	0.543	0.135	0.044	YZ	0.435
0%		0	4	0	1.32	0.219	0.390	0.540	0.138	0.042	Z	0.434
S - 0 pphm	8	0	0	1	1.35	0.242	0.437	0.516	0.135	0.049		0.439
10 pphm		0	0	2	1.31	0.242	0.446	0.565	0.134	0.048		0.434
O x S	2	0	1	1	1.35	0.253	0.537	0.540	0.142	0.060		0.461
		0	2	1	1.33	0.259	0.433	0.522	0.127	0.050		0.432
		0	3	1	1.43	0.249	0.395	0.492	0.137	0.044		0.409
		0	4	1	1.31	0.208	0.382	0.512	0.134	0.041		0.454
		0	1	2	1.38	0.235	0.451	0.525	0.134	0.051		0.390
		0	2	2	1.19	0.245	0.453	0.570	0.127	0.052		0.471
		0	3	2	1.35	0.258	0.483	0.594	0.132	0.044		0.461
		0	4	2	1.33	0.230	0.398	0.569	0.142	0.044		0.414

Table 28. (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

Source	df	Species AB	BM	BR	BRI	BT	FM	HL
B	1	23.550	0.828	0.682	0.004	1.287*	0.000	4.261
O	3	13.050	0.034	7.172	0.125	0.108	0.156**	0.471
O_L	1	1.358	1.269	21.110	0.085	0.005	0.418***	0.055
O_Q	1	0.962	1.774	0.014	0.249	0.210	0.012	0.717
O_C	1	36.840	0.060	0.396	0.040	0.108	0.039	0.642
S	1	6.169	0.001	0.341	9.230	0.009	0.003	0.100
OxS	3	6.374	0.366	5.200	2.314	0.052	0.030	3.584
O_LxS	1	0.038	0.946	6.218	3.152	0.127	0.067*	0.505
O_QxS	1	17.110	0.018	8.187	3.007	0.005	0.014	10.220
O_CxS	1	1.970	0.135	1.196	0.783	0.025	0.009	0.031
Error	7	57.070	1.034	5.274	3.418	0.109	0.009	2.001
C.V. (%)		17.9	13.3	16.4	10.8	7.8	6.3	10.2

* = Significance at .05
** = Significance at .01
*** = Significance at .001

[1]Mean squares have been multiplied by 1000 for presentation.

Table 29. Basic biomass and quality study summary: analysis of variation in yield parameters of cool-season annual range grasses (7).

A. Means.

Combination	Count per Mean	Subclass B O S	GDW Yield	Tiller Number	GDW/ Tiller
B	8	1 0 0	20.48	75.70	0.270
		2 0 0	20.55	74.41	0.277
O - 100%	4	0 1 0	20.84	71.53	0.291
67%		0 2 0	20.81	77.93	0.267
33%		0 3 0	20.72	74.13	0.280
0%		0 4 0	19.68	76.65	0.257
S - 0 pphm	8	0 0 1	20.44	75.59	0.271
10 pphm		0 0 2	20.58	74.53	0.276
O x S	2	0 1 1	22.36	75.45	0.297
		0 2 1	20.49	77.60	0.264
		0 3 1	19.98	72.20	0.278
		0 4 1	18.95	77.10	0.246
		0 1 2	19.32	67.60	0.285
		0 2 2	21.14	78.25	0.270
		0 3 2	21.47	76.05	0.282
		0 4 2	20.41	76.20	0.268

Table 29. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	GDW Yield	Tiller Number	GDW/ Tiller[1]
B	1	0.021	6.631	0.153
0	3	1.246	32.140	0.890
0_L	1	2.718	38.210	1.979
0_Q	1	0.998	15.140	0.001
0_C	1	0.021	43.070	0.689
S	1	0.078	4.516	0.110
0xS	3	4.631	24.390	0.190
0_LxS	1	10.300	26.620	0.541
0_QxS	1	3.585	44.740	0.000
0_CxS	1	0.002	1.807	0.030
Error	7	4.824	30.730	0.371
C.V. (%)		10.7	7.4	7.0

[1] Mean squares have been multiplied by 1000 for presentation.

Table 30. Basic biomass and quality study: analysis of variation in percentage total nonstructural carbohydrate content in 7 range grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	O	S	AB	BM	BR	BRI	BT	FM	HL
B	8	1	0	0	16.21	9.80	11.60	13.53	6.22	7.99	17.79
		2	0	0	15.87	9.60	11.08	15.53	5.39	8.77	18.86
O - 100%	4	0	1	0	16.52 y	9.76	11.99	16.31	6.17	7.21	19.17
67%		0	2	0	17.71 y	9.89	12.45	14.02	6.74	9.81	18.97
33%		0	3	0	16.68 y	9.86	11.12	13.61	5.44	8.36	17.82
0%		0	4	0	13.24 z	9.29	9.81	14.18	4.87	8.15	17.35
S - 0 pphm	8	0	0	1	16.62	9.87	12.34	14.34	6.53	8.15	18.00
10 pphm		0	0	2	15.45	9.53	10.35	14.73	5.08	8.62	18.65
O x S	2	0	1	1	17.82	9.81	12.83	16.36	6.69	6.49	19.17
		0	2	1	16.15	11.21	14.08	14.39	8.36	10.44	18.97
		0	3	1	18.65	9.40	12.00	12.31	6.28	8.15	17.30
		0	4	1	13.87	9.08	10.44	14.29	4.82	7.52	16.57
		0	1	2	15.22	9.71	11.15	16.26	5.65	7.94	19.18
		0	2	2	19.28	8.57	10.83	13.66	5.13	9.19	18.97
		0	3	2	14.70	10.33	10.23	14.91	4.61	8.57	18.34
		0	4	2	12.62	9.50	9.19	14.08	4.92	8.77	18.13

Table 30. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		AB	BM	BR	BRI	BT	FM	HL
B	1	0.456	0.150	1.092	16.000*	2.772	2.426	4.548
0	3	15.010*	0.314	5.398	5.866	2.690	4.618	3.111
0_L	1	23.680**	0.451	11.400*	9.231	4.569	0.843	7.946
0_Q	1	20.890*	0.485	2.978	8.363	1.237	7.844	0.051
0_C	1	0.465	0.005	1.820	0.004	2.265	5.168	1.337
S	1	5.452	0.487	15.800*	0.608	8.468*	0.879	1.697
0xS	3	9.409*	2.522	0.755	2.235	1.933	1.513	0.606
0_LxS	1	0.005	0.643	0.242	0.098	1.021	0.006	1.468
0_QxS	1	2.172	0.973	1.057	1.232	3.852	3.091	0.061
0_CxS	1	26.050**	5.949	0.965	5.375	0.925	1.442	0.290
Error	7	1.780	3.348	1.538	1.939	0.847	1.720	5.282
C.V. (%)		8.3	18.9	10.9	9.6	15.8	15.6	12.5

* = Significance at .05
** = Significance at .01

Table 31. Basic biomass and quality study: analysis of variation in percentage crude protein content in 7 range grass species.

A. Means.

Combination	Count per Mean	Subclass B	Subclass O	Subclass S	AB	BM	BR	BRI	BT	FM	HL
B	8	1	0	0	5.84	10.81	6.13	7.94	12.79	9.28	8.31
		2	0	0	5.69	11.20	6.32	8.01	12.83	9.28	8.17
O - 100%	4	0	1	0	5.53	10.75	5.91 z	7.58	12.23	8.97 z	8.08
67%		0	2	0	5.44	10.65	6.06 z	7.96	12.80	8.90 z	8.28
33%		0	3	0	5.25	11.29	6.11 z	8.25	12.74	9.59 y	8.17
0%		0	4	0	6.84	11.33	6.80 y	8.12	13.47	9.67 y	8.42
S - 0 pphm	8	0	0	1	5.70	10.77	6.22	8.08	12.67	9.28	8.29
10 pphm		0	0	2	5.84	11.24	6.22	7.88	12.95	9.29	8.18
O x S	2	0	1	1	5.74	10.73	6.00	7.71	11.94	8.92	8.04
		0	2	1	5.64	10.17	5.73	7.95	12.59	9.35	8.42
		0	3	1	4.85	10.89	6.30	8.39	12.64	9.30	8.05
		0	4	1	6.55	11.29	6.87	8.26	13.53	9.53	8.67
		0	1	2	5.33	10.77	5.82	7.46	12.53	9.00	8.13
		0	2	2	5.24	11.14	6.39	7.97	13.01	8.46	8.14
		0	3	2	5.66	11.70	5.93	8.11	12.85	9.89	8.28
		0	4	2	7.13	11.36	6.73	7.98	13.40	9.81	8.18

Table 31. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		AB	BM	BR	BRI	BT	FM	HL
B	1	0.090	0.608	0.144	0.018	0.005	0.000	0.081
0	3	2.099	0.499	0.628*	0.333	1.023	0.646*	0.087
0_L	1	3.208	0.922*	1.592**	0.662	2.911	1.286*	0.199
0_Q	1	2.775	0.013	0.274	0.263	0.211	0.016	0.003
0_C	1	0.314	0.562	0.019	0.073	0.137	0.637	0.059
S	1	0.078	0.884	0.000	0.158	0.297	0.000	0.051
0xS	3	0.412	0.237	0.209	0.021	0.097	0.409	0.110
0_LxS	1	0.697	0.000	0.011	0.004	0.283	0.115	0.118
0_QxS	1	0.018	0.696	0.086	0.016	0.005	0.093	0.030
0_CxS	1	0.522	0.014	0.529*	0.042	0.004	1.019*	0.180
Error	7	0.787	0.164	0.075	0.125	0.838	0.133	0.461
C.V. (%)		15.4	3.7	4.4	4.4	7.1	3.9	8.2

* = Significance at .05
** = Significance at .01

Table 32. Basic biomass and quality study: analysis of variation in percentage crude fiber content in 7 range grass species.

A. Means.

Combination	Count per Mean	Subclass B	O	S	Species AB	BM	BR	BRI	BT	FM	HL
B	8	1	0	0	28.87	23.89	31.83	25.54	22.90	25.76	24.48
		2	0	0	28.93	22.69	32.11	24.86	22.72	25.24	23.35
O – 100%	4	0	1	0	28.68	22.79	32.78	24.56	22.89	26.04	23.83
67%		0	2	0	28.40	23.05	31.29	25.59	22.26	25.53	23.85
33%		0	3	0	29.23	23.90	32.27	25.71	22.85	25.10	24.17
0%		0	4	0	29.28	23.42	31.53	24.95	23.26	25.33	23.82
S – 0 pphm	8	0	0	1	28.87	23.48	31.18	25.20	22.44	25.76	23.84
10 pphm		0	0	2	28.93	23.09	32.76	25.21	23.19	25.24	24.00
O x S	2	0	1	1	27.74	23.49	33.20	24.86	22.48	26.97	24.12
		0	2	1	29.83	21.99	30.04	25.14	21.97	25.33	23.63
		0	3	1	29.35	25.62	31.10	26.03	22.37	25.05	24.04
		0	4	1	28.58	22.85	30.37	24.77	22.95	25.68	23.57
		0	1	2	29.63	22.09	32.36	24.27	23.30	25.10	23.54
		0	2	2	26.98	24.11	32.54	26.05	22.55	25.74	24.08
		0	3	2	29.12	22.18	33.44	25.38	23.33	25.15	24.31
		0	4	2	29.99	23.99	32.70	25.14	23.58	24.97	24.07

Table 32. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		AB	BM	BR	BRI	BT	FM	HL
B	1	0.011	5.724	0.308	1.870	0.128	1.061	5.119*
0	3	0.733	0.925	1.865	1.171	0.694	0.640	0.117
0_L	1	1.081	1.149	2.232	0.309	0.458	1.181	0.004
0_Q	1	0.099	0.572	0.575	3.200	1.072	0.554	0.149
0_C	1	1.021	1.055	2.787	0.003	0.551	0.184	0.198
S	1	0.012	0.612	10.050	0.001	2.228*	1.061	0.101
0xS	3	4.554*	6.325*	2.619	0.580	0.031	1.041	0.253
0_LxS	1	0.000	1.224	4.734	0.232	0.009	0.569	0.533
0_QxS	1	10.040**	0.299	2.869	0.055	0.002	2.419*	0.159
0_CxS	1	3.621	17.450**	0.255	1.453	0.081	0.135	0.067
Error	7	0.674	1.324	1.862	1.002	0.293	0.291	0.477
C.V. (%)		2.8	4.9	4.3	4.0	2.4	2.1	2.9

* = Significance at .05
** = Significance at .01

Table 33. Basic biomass and quality study summary: analysis of variation in general nutritional factors of cool-season annual range grasses (7).

A. Means.

Combination	Count per Mean	Subclass B	Subclass O	Subclass S	Percentage TNC	Percentage C. P.	Percentage C. F.
B	8	1	0	0	11.86	8.73	25.98
		2	0	0	12.16	8.78	25.69
O - 100%	4	0	1	0	12.46 Y	8.44	25.94
67%		0	2	0	12.76 Y	8.58	25.44
33%		0	3	0	11.84 YZ	8.77	26.03
0%		0	4	0	10.98 Z	9.22	25.94
S - 0 pphm	8	0	0	1	12.25	8.71	25.61
10 pphm		0	0	2	11.77	8.80	26.06
O x S	2	0	1	1	12.76	8.44	26.12
		0	2	1	13.30	8.55	24.87
		0	3	1	12.01	8.63	25.93
		0	4	1	10.94	9.24	25.54
		0	1	2	12.16	8.45	25.75
		0	2	2	12.23	8.62	26.01
		0	3	2	11.67	8.91	26.13
		0	4	2	11.03	9.21	26.34

Table 33. (Cont.)

B. Sources of variation (with associated df) and mean squares.

		Percentage		
Source	df	TNC	C. P.	C. F.
B	1	0.345	0.010	0.348
0	3	2.468**	0.462	0.290
0_L	1	5.246**	1.289*	0.023
0_Q	1	1.282	0.090	0.162
0_C	1	0.877	0.006	0.685
S	1	0.926	0.026	0.783
0xS	3	0.232	0.020	0.446
0_LxS	1	0.328	0.000	0.489
0_QxS	1	0.188	0.037	0.204
0_CxS	1	0.180	0.021	0.646
Error	7	0.237	0.118	0.256
C.V. (%)		4.1	3.9	2.0

* = Significance at .05
** = Significance at .01

Table 34: Basic biomass and quality study: analysis of variation percentage in calcium content in 7 range grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	0	S	AB	BM	BR	BRI	BT	FM	HL
B	8	1	0	0	0.231	0.567	0.125	0.524	0.617	0.316	0.423
		2	0	0	0.220	0.505	0.111	0.507	0.640	0.286	0.437
0 - 100%	4	0	1	0	0.240	0.461	0.115	0.489	0.634	0.308	0.434
67%		0	2	0	0.213	0.527	0.106	0.522	0.594	0.277	0.423
33%		0	3	0	0.217	0.598	0.122	0.541	0.627	0.280	0.420
0%		0	4	0	0.231	0.559	0.129	0.509	0.660	0.345	0.442
S - 0 pphm	8	0	0	1	0.224	0.607	0.113	0.520	0.618	0.306	0.435
10 pphm		0	0	2	0.227	0.466	0.123	0.511	0.640	0.299	0.424
0 x S	2	0	1	1	0.248	0.478	0.101	0.464	0.643	0.318	0.422
		0	2	1	0.203	0.594	0.077	0.529	0.559	0.279	0.424
		0	3	1	0.208	0.708	0.142	0.590	0.641	0.300	0.429
		0	4	1	0.236	0.646	0.132	0.496	0.627	0.329	0.465
		0	1	2	0.232	0.443	0.129	0.513	0.626	0.299	0.445
		0	2	2	0.223	0.459	0.134	0.515	0.628	0.276	0.422
		0	3	2	0.227	0.488	0.102	0.492	0.612	0.260	0.411
		0	4	2	0.226	0.472	0.127	0.522	0.692	0.361	0.419

Table 34. (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

Source	df	Species						
		AB	BM	BR	BRI	BT	FM	HL
B	1	0.564	15.500	0.798	1.139	2.186	4.356	0.798
0	3	0.632	13.580	0.410	1.960	2.964	3.964	0.409
0_L	1	0.114	23.450	0.591	1.085	1.930	2.752	0.123
0_Q	1	1.706	11.590	0.268	4.323	5.330	9.120	1.068
0_C	1	0.076	5.696	0.371	0.470	1.632	0.020	0.035
S	1	0.039	79.520*	0.410	0.352	1.958	0.225	0.452
0xS	3	0.365	6.234	1.768	4.159	2.774	0.923	0.848
0_LxS	1	0.017	11.370	1.207	0.618	2.075	0.983	2.537
0_QxS	1	1.075	5.611	0.013	8.820*	0.019	0.779	0.001
0_CxS	1	0.003	1.721	4.085	3.039	6.228	1.007	0.008
Error	7	0.780	7.015	0.815	1.017	2.495	1.654	0.475
C.V. (%)		12.4	15.6	24.2	6.2	7.9	13.4	5.1

* = Significance at .05

[1]Mean squares have been multiplied by 1000 for presentation.

Table 35. Basic biomass and yield study: analysis of variation in percentage magnesium content in 7 range grass species.

A. Means.

Combination	Count per Mean	Subclass B	Subclass O	Subclass S	Species AB	BM	BR	BRI	BT	FM	HL
B	8	1	0	0	0.165	0.178	0.098	0.128	0.271	0.122	0.220
		2	0	0	0.165	0.158	0.091	0.129	0.293	0.125	0.228
0 - 100%	4	0	1	0	0.180	0.173	0.093	0.130	0.300	0.142	0.234
67%		0	2	0	0.154	0.153	0.092	0.124	0.280	0.121	0.224
33%		0	3	0	0.164	0.173	0.095	0.130	0.275	0.114	0.211
0%		0	4	0	0.163	0.173	0.098	0.130	0.273	0.118	0.226
S - 0 ppm	8	0	0	1	0.160	0.173	0.096	0.130	0.280	0.126	0.230
10 ppm		0	0	2	0.170	0.163	0.093	0.127	0.284	0.121	0.218
0 x S	2	0	1	1	0.177	0.172	0.089	0.126	0.315	0.139	0.228
		0	2	1	0.137	0.145	0.085	0.123	0.254	0.120	0.228
		0	3	1	0.159	0.192	0.104	0.135	0.280	0.120	0.225
		0	4	1	0.168	0.183	0.105	0.136	0.271	0.125	0.239
		0	1	2	0.182	0.174	0.097	0.133	0.285	0.145	0.240
		0	2	2	0.172	0.160	0.098	0.125	0.306	0.122	0.220
		0	3	2	0.168	0.154	0.087	0.125	0.270	0.107	0.197
		0	4	2	0.157	0.162	0.091	0.124	0.275	0.111	0.212

Table 35. (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

Source	df	Species						
		AB	BM	BR	BRI	BT	FM	HL
B	1	0.002	1.541	0.218	0.002	1.892	0.033	0.218
0	3	0.446	0.417	0.032	0.035	0.593	0.656	0.361
0_L	1	0.449	0.020	0.063	0.003	1.440	1.269*	0.219
0_Q	1	0.593	0.380	0.017	0.032	0.338	0.684	0.601
0_C	1	0.295	0.851	0.016	0.070	0.000	0.016	0.263
S	1	0.352	0.431	0.023	0.046	0.056	0.086	0.638
0xS	3	0.372	0.574	0.229	0.083	1.207	0.102	0.366
0_LxS	1	0.210	0.537	0.336	0.205*	0.251	0.246	0.872
0_QxS	1	0.650	0.005	0.001	0.006	1.110	0.002	0.135
0_CxS	1	0.256	1.180	0.350	0.037	2.261	0.059	0.090
Error	7	0.620	0.317	0.273	0.022	0.437	0.161	0.235
C.V. (%)		15.1	10.6	17.4	3.6	7.4	10.2	6.8

* = Significance at .05

[1]Mean squares have been multiplied by 1000 for presentation.

Table 36. Basic biomass and quality study: analysis of variation in percentage phosphorus content in 7 forage grass species.

A. Means.

Combination	Count per Mean	B	O	S	AB	BM	BR	BRI	BT	FM	HL
B	8	1	0	0	0.249	0.506	0.221	0.347	0.504	0.268	0.282
		2	0	0	0.236	0.451	0.263	0.331	0.580	0.259	0.308
O - 100%	4	0	1	0	0.233	0.491	0.226	0.320	0.539	0.263 yz	0.299
67%		0	2	0	0.231	0.437	0.251	0.336	0.540	0.250 z	0.298
33%		0	3	0	0.239	0.492	0.243	0.337	0.521	0.260 z	0.275
0%		0	4	0	0.265	0.495	0.247	0.363	0.569	0.282 y	0.308
S - 0 pphm	8	0	0	1	0.235	0.477	0.249	0.341	0.539	0.267	0.304
10 pphm		0	0	2	0.249	0.480	0.235	0.337	0.546	0.260	0.287
O x S	2	0	1	1	0.228	0.472	0.237	0.322	0.528	0.265	0.299
		0	2	1	0.215	0.409	0.252	0.341	0.522	0.252	0.300
		0	3	1	0.231	0.509	0.244	0.339	0.518	0.267	0.283
		0	4	1	0.266	0.518	0.264	0.362	0.587	0.283	0.332
		0	1	2	0.238	0.509	0.215	0.318	0.549	0.260	0.299
		0	2	2	0.248	0.465	0.251	0.332	0.557	0.248	0.296
		0	3	2	0.247	0.474	0.242	0.334	0.524	0.252	0.266
		0	4	2	0.264	0.472	0.229	0.363	0.552	0.281	0.285

Table 36. (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

Source	df	Species						
		AB	BM	BR	BRI	BT	FM	HL
B	1	0.716	12.100*	7.014**	1.139	23.100**	0.342	2.730
0	3	0.962	3.038	0.478	1.236	1.613	0.709*	0.817
0_L	1	2.158*	0.385	0.700	3.526*	1.474	0.849*	0.053
0_Q	1	0.715	3.109	0.480	0.085	2.242	1.199*	1.220
0_C	1	0.013	5.620	0.253	0.097	1.122	0.079	1.178
S	1	0.827	0.036	0.856	0.077	0.182	0.182	1.173
0xS	3	0.211	2.580	0.267	0.016	0.915	0.036	0.448
0_LxS	1	0.120	4.703	0.091	0.011	1.832	0.001	1.182
0_QxS	1	0.403	0.208	0.711	0.033	0.727	0.043	0.153
0_CxS	1	0.110	2.828	0.000	0.004	0.185	0.064	0.010
Error	7	0.356	2.158	0.354	0.321	1.459	0.147	0.678
C.V. (%)		7.8	9.7	7.8	5.3	7.0	4.6	8.8

* = Significance at .05
** = Significance at .01

[1]Mean squares have been multiplied by 1000 for presentation.

Table 37. Basic biomass and quality study summary: analysis of variation in mineral components of cool-season annual range grasses (7).

A. Means.

Combination	Count per Mean	Subclass			Percentage		
					Ca	Mg	P
		B	0	S			
B	8	1	0	0	0.401	0.167	0.340
		2	0	0	0.382	0.170	0.347
0 - 100%	4	0	1	0	0.383	0.179	0.339
67%		0	2	0	0.372	0.160	0.335
33%		0	3	0	0.401	0.166	0.338
0%		0	4	0	0.411	0.169	0.361
S - 0 pphm	8	0	0	1	0.403	0.169	0.345
10 pphm		0	0	2	0.380	0.168	0.342
0 x S	2	0	1	1	0.382	0.178	0.336
		0	2	1	0.381	0.149	0.327
		0	3	1	0.431	0.173	0.342
		0	4	1	0.419	0.175	0.373
		0	1	2	0.384	0.179	0.341
		0	2	2	0.362	0.172	0.342
		0	3	2	0.370	0.158	0.334
		0	4	2	0.402	0.162	0.349

Table 37. (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

		Percentage		
Source	df	Ca	Mg	P
B	1	1.406	0.023	0.203
0	3	1.231	0.241	0.583
0_L	1	2.112	0.162	1.051
0_Q	1	0.411	0.454	0.698
0_C	1	1.169	0.106	0.000
S	1	2.209	0.005	0.028
0xS	3	0.710	0.311	0.279
0_LxS	1	0.313	0.219	0.532
0_QxS	1	1.081	0.098	0.154
0_CxS	1	0.736	0.615	0.150
Error	7	0.488	0.217	0.198
C.V. (%)		5.6	8.7	4.1

[1]Mean squares have been multiplied by 1000 for presentation.

Table 38. Grazing simulation study: analysis of variation in gram dry weight yield in 7 range grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	P	C	AB	BM	BR	BRI	BT	FM	HL
B	4	1	0	0	28.60	10.41	21.18	17.43	9.17	8.79	19.11
		2	0	0	33.41	11.32	21.55	18.60	8.76	9.53	18.23
P -	4	0	1	0	32.44	10.67	21.25	17.89	9.17	10.08	18.25
+		0	2	0	29.57	11.06	21.48	18.14	8.76	8.23	19.08
C -		0	0	1	42.72	12.85	30.73	21.89	10.70	11.48	22.98
+		0	0	2	19.29	8.88	12.00	14.14	7.24	6.83	14.35
P x C	2	0	1	1	44.40	13.02	31.30	21.40	10.84	13.26	22.27
		0	2	1	41.05	12.68	30.17	22.39	10.56	9.71	23.70
		0	1	2	20.49	8.32	11.21	14.38	7.50	6.91	14.23
		0	2	2	18.08	9.44	12.79	13.90	6.97	6.76	14.47

Table 38. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		AB	BM	BR	BRI	BT	FM	HL
B	1	46.320	1.665	0.266	2.750	0.340	1.103	1.549
P	1	16.560	0.300	0.101	0.127	0.332	6.827	1.395
C	1	1098.600**	31.560**	702.000**	120.200**	23.980**	43.200**	149.100**
P x C	1	0.437	1.059	3.672	1.073	0.030	5.797	0.720
Error	3	12.710	0.729	4.305	3.444	0.591	0.802	1.570
C. V. (%)		11.5	7.9	9.7	10.3	8.6	9.8	6.7

** = Significance at .01

Table 39. Grazing simulation study: analysis of variation in number of tillers produced in 7 range grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	P	C	AB	BM	BR	BRI	BT	FM	HL
B	4	1	0	0	35.65	54.45	70.80	48.35	74.60	193.7	53.65
		2	0	0	40.55	56.75	63.35	47.25	75.60	214.1	58.40
P −	4	0	1	0	39.35	56.30	62.93	47.05	73.45	197.9	54.00
+		0	2	0	36.85	54.90	71.23	48.55	76.45	209.9	58.05
C −		0	0	1	31.95	50.20	60.68	38.75	78.10	220.6	49.90
+		0	0	2	44.25	61.00	73.48	56.85	72.10	187.2	62.15
P x C	2	0	1	1	33.60	51.30	58.80	39.80	76.00	220.3	48.30
		0	2	1	30.30	49.10	62.55	37.70	80.20	220.9	51.0
		0	1	2	45.10	61.30	67.05	54.30	70.90	175.4	59.70
		0	2	2	43.40	60.70	79.90	59.40	73.30	198.9	64.60

Table 39. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		AB	BM	BR	BRI	BT	FM	HL
B	1	48.020	10.580	111.000	2.420	2.000	836.400	45.120
P	1	12.500	3.920	137.800	4.500	21.780	290.400	32.800
C	1	302.600	233.300**	327.700*	655.200**	72.000	2237.800	300.100
P x C	1	1.280	1.280	41.410	25.920	1.620	262.200	1.445
Error	3	59.340	3.913	26.790	15.340	30.970	392.000	48.230
C. V. (%)		20.2	3.6	7.7	8.2	7.4	9.7	12.4

* = Significance at .05
** = Significance at .01

Table 40. Grazing simulation study: analysis of variation in gram dry weight per tiller in 7 range grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	P	C	AB	BM	BR	BRI	BT	FM	HL
B	4	1	0	0	0.843	0.197	0.310	0.386	0.122	0.045	0.364
		2	0	0	0.948	0.204	0.367	0.430	0.115	0.044	0.330
P –	4	0	1	0	0.905	0.195	0.352	0.402	0.124	0.050	0.352
+		0	2	0	0.886	0.207	0.324	0.414	0.114	0.039	0.343
C –		0	0	1	1.353	0.256	0.512	0.567	0.137	0.052	0.461
+		0	0	2	0.438	0.146	0.164	0.249	0.100	0.037	0.233
P x C	2	0	1	1	1.352	0.253	0.537	0.540	0.142	0.060	0.461
		0	2	1	1.353	0.258	0.487	0.594	0.132	0.044	0.461
		0	1	2	0.458	0.136	0.167	0.264	0.106	0.039	0.242
		0	2	2	0.419	0.156	0.160	0.234	0.095	0.034	0.224

Table 40. (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

Source	df	Species						
		AB	BM	BR	BRI	BT	FM	HL
B	1	22.310	0.093	6.474	4.004	0.097	0.001	2.234
P	1	0.732	0.294	1.624	0.261	0.217	0.233**	0.160
C	1	1672.200**	24.220***	242.900**	202.600***	2.701	0.473**	104.000***
P x C	1	0.818	0.116	0.921	3.494	0.000	0.058*	0.165
Error	3	39.240	0.080	3.540	1.153	0.057	0.005	0.548
C. V. (%)		22.1	4.4	17.6	8.3	6.4	5.1	6.7

*   = Significance at .05
** = Significance at .01
*** = Significance at .001

[1]Mean squares have been multiplied by 1000 for presentation.

Table 41. Grazing simulation study: analysis of variation in percentage total nonstructural carbohydrate content in 7 range grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	P	C	AB	BM	BR	BRI	BT	FM	HL
B	4	1	0	0	14.94	8.82	7.56	10.54	4.20	7.01	15.64
		2	0	0	14.29	10.33	7.84	11.06	4.46	7.63	15.38
P -	4	0	1	0	15.05	9.29	8.36	11.06	4.92	6.12	15.38
+		0	2	0	14.18	9.86	7.06	10.54	3.73	8.51	15.64
C -		0	0	1	16.26	10.07	11.53	15.63	5.65	7.53	18.76
+		0	0	2	12.97	9.08	3.89	5.96	3.00	7.11	12.26
P x C	4	0	1	1	17.82	9.81	12.83	16.36	6.69	6.49	19.17
		0	2	1	14.70	10.33	10.23	14.91	4.61	8.57	18.34
	2	0	1	2	12.28	8.77	3.89	5.76	3.16	5.76	11.58
		0	2	2	13.66	9.40	3.89	6.17	2.85	8.46	12.93

Table 41. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		AB	BM	BR	BRI	BT	FM	HL
B	1	0.865	4.545	0.135	0.541	0.135	0.775	0.135
P	1	1.505	0.656	3.380*	0.541	2.856**	11.450	0.135
C	1	21.680*	1.950	116.900***	187.000**	14.050***	0.349	84.500*
P x C	1	10.150	0.006	3.380*	1.748	1.566*	0.195	2.376
Error	3	1.341	3.741	0.150	1.521	0.077	2.643	4.520
C. V. (%)		7.9	20.2	5.0	11.4	6.4	22.2	13.7

* = Significance at .05
** = Significance at .01
*** = Significance at .001

Table 42. Grazing simulation study: analysis of variation in percentage crude protein content in 7 range grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	P	C	AB	BM	BR	BRI	BT	FM	HL
B	4	1	0	0	7.64	12.41	7.84	9.34	13.54	10.42	9.70
		2	0	0	7.16	11.84	7.94	9.18	13.69	9.98	9.31
P –	4	0	1	0	7.42	11.71	7.90	9.41	13.54	10.08	9.40
+		0	2	0	7.38	12.54	7.88	9.13	13.69	10.33	9.61
C –		0	0	1	5.70	11.21	5.92	7.91	12.39	9.42	8.16
+		0	0	2	9.10	13.04	9.86	10.63	14.84	10.99	10.85
P x C	2	0	1	1	5.74	10.73	6.00	7.71	11.94	8.95	8.04
		0	2	1	5.66	11.70	5.84	8.11	12.85	9.89	8.28
		0	1	2	9.10	12.69	9.80	11.12	15.14	11.21	10.77
		0	2	2	9.10	13.39	9.93	10.15	14.53	10.77	10.94

Table 42. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		AB	BM	BR	BRI	BT	FM	HL
B	1	0.466	0.644	0.021	0.060	0.045	0.392	0.304
P	1	0.004	1.386*	0.001	0.160	0.045	0.128	0.088
C	1	36.000*	6.680**	31.170**	14.880**	11.960*	4.914*	14.530**
P x C	1	0.004	0.035	0.041	0.932	1.155	0.959	0.002
Error	3	1.097	0.104	0.211	0.198	0.439	0.452	0.283
C. V. (%)		29.3	2.7	5.8	4.8	4.9	6.6	5.6

* = Significance at .05
** = Significance at .01

Table 43. Grazing simulation study: analysis of variation in percentage crude fiber content in 7 range grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	P	C	AB	BM	BR	BRI	BT	FM	HL
B	4	1	0	0	26.09	22.40	30.12	25.40	23.10	26.22	24.48
		2	0	0	26.17	21.71	30.68	25.35	22.28	25.89	24.30
P -	4	0	1	0	25.93	22.48	30.13	25.18	22.57	26.83	24.38
+		0	2	0	26.33	21.63	30.66	25.57	22.81	25.29	24.40
C -		0	0	1	28.43	22.84	33.32	25.12	22.90	26.06	24.20
+		0	0	2	23.83	21.28	27.47	25.63	22.48	26.05	24.58
P x C	2	0	1	1	27.74	23.49	33.20	24.86	22.48	26.97	24.09
		0	2	1	29.12	22.18	33.44	25.38	23.33	25.15	24.31
		0	1	2	24.12	21.48	27.07	25.51	22.67	26.68	24.67
		0	2	2	23.54	21.09	27.88	25.76	22.30	25.43	24.50

Table 43. (Cont.)

B. Sources of variation (with associated df) and mean squares.

Source	df	Species						
		AB	BM	BR	BRI	BT	FM	HL
B	1	0.014	0.952	0.633	0.005	1.361*	0.215	0.070
P	1	0.316	1.445	0.557	0.304	0.115	4.728	0.001
C	1	42.370**	4.836	68.390**	0.530	0.353	0.000	0.293
P x C	1	1.911	0.423	0.165	0.036	0.744	0.160	0.074
Error	3	1.092	1.046	1.137	0.460	0.111	0.269	1.267
C. V. (%)		4.0	4.6	3.5	2.7	1.5	2.0	4.6

* = Significance at .05
** = Significance at .01

Table 44. Grazing simulation study: analysis of variation in percentage calcium content in 7 range grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	P	C	AB	BM	BR	BRI	BT	FM	HL
B	4	1	0	0	0.276	0.475	0.236	0.512	0.625	0.356	0.425
		2	0	0	0.259	0.487	0.250	0.479	0.669	0.344	0.422
P –	4	0	1	0	0.277	0.490	0.247	0.497	0.669	0.371	0.433
+		0	2	0	0.257	0.472	0.238	0.494	0.624	0.329	0.414
C –		0	0	1	0.238	0.483	0.101	0.478	0.627	0.289	0.416
+		0	0	2	0.297	0.479	0.384	0.513	0.666	0.411	0.431
P x C	2	0	1	1	0.248	0.478	0.101	0.464	0.643	0.318	0.422
		0	2	1	0.227	0.488	0.102	0.492	0.612	0.260	0.411
		0	1	2	0.305	0.503	0.394	0.529	0.695	0.424	0.444
		0	2	2	0.288	0.455	0.375	0.497	0.636	0.399	0.418

Table 44. (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

Source	df	Species						
		AB	BM	BR	BRI	BT	FM	HL
B	1	0.578	0.288	0.450	2.278	3.872	0.313	0.013
P	1	0.761	0.685	0.162	0.010	4.050	3.445	0.685
C	1	6.962	0.032	160.200***	2.346	2.965	30.010*	0.420
P x C	1	0.008	1.682	0.200	1.830	0.392	0.545	0.113
Error	3	1.023	0.184	0.206	0.669	2.341	1.269	0.141
C. V. (%)		12.0	2.8	5.9	5.2	7.5	10.2	2.8

* = Significance at .05
*** = Significance at .001

[1]Mean square have been multiplied by 1000 for presentation.

Table 45. Grazing simulation study: analysis of variation in percentage magnesium content in 7 range grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	P	C	AB	BM	BR	BRI	BT	FM	HL
B	4	1	0	0	0.224	0.147	0.157	0.160	0.317	0.154	0.214
		2	0	0	0.212	0.145	0.150	0.158	0.324	0.157	0.231
P -	4	0	1	0	0.223	0.155	0.158	0.162	0.333	0.164	0.241
+		0	2	0	0.213	0.137	0.149	0.156	0.308	0.147	0.204
C -		0	0	1	0.173	0.163	0.088	0.126	0.292	0.123	0.212
+		0	0	2	0.263	0.129	0.219	0.192	0.349	0.188	0.233
P x C	2	0	1	1	0.177	0.172	0.089	0.126	0.315	0.139	0.228
		0	2	1	0.168	0.154	0.087	0.125	0.270	0.107	0.197
		0	1	2	0.269	0.138	0.226	0.197	0.351	0.189	0.254
		0	2	2	0.258	0.119	0.211	0.187	0.346	0.186	0.211

Table 45. (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

Source	df	Species						
		AB	BM	BR	BRI	BT	FM	HL
B	1	0.288	0.010	0.078	0.010	0.084	0.021	0.630
P	1	0.200	0.666	0.153	0.066	1.250**	0.595	2.701
C	1	16.380**	2.346	34.190**	8.911***	6.384***	8.256**	0.820
P x C	1	0.002	0.001	0.078	0.036	0.800**	0.435	0.066
Error	3	0.458	0.294	0.562	0.016	0.020	0.064	1.365
C. V. (%)		9.8	11.7	15.4	2.5	1.4	5.1	16.6

** = Significance at .01
*** = Significance at .001

[1]Mean squares have been multiplied by 1000 for presentation.

Table 46. Grazing simulation study: analysis of variation in percentage phosphorus content in 7 range grass species.

A. Means.

Combination	Count per Mean	Subclass			Species						
		B	P	C	AB	BM	BR	BRI	BT	FM	HL
B	4	1	0	0	0.367	0.492	0.304	0.419	0.558	0.300	0.361
		2	0	0	0.347	0.455	0.323	0.414	0.568	0.295	0.366
P -	4	0	1	0	0.355	0.481	0.316	0.417	0.564	0.311	0.382
+		0	2	0	0.359	0.466	0.311	0.415	0.562	0.284	0.346
C -		0	0	1	0.238	0.473	0.240	0.328	0.526	0.259	0.283
+		0	0	2	0.476	0.474	0.387	0.505	0.600	0.336	0.445
P x C	2	0	1	1	0.228	0.472	0.237	0.322	0.528	0.265	0.299
		0	2	1	0.247	0.474	0.242	0.334	0.524	0.252	0.266
		0	1	2	0.481	0.490	0.395	0.513	0.600	0.356	0.465
		0	2	2	0.471	0.457	0.380	0.497	0.600	0.317	0.425

Table 46. (Cont.)

B. Sources of variation (with associated df) and mean squares.[1]

Source	df	Species						
		AB	BM	BR	BRI	BT	FM	HL
B	1	0.741	2.628	0.780	0.041	0.190	0.055	0.050
P	1	0.045	0.496	0.045	0.008	0.010	1.378	2.665
C	1	114.000**	0.000	43.660***	62.660***	10.880*	12.090*	52.490**
P x C	1	0.435	0.630	0.210	0.392	0.010	0.325	0.025
Error	3	0.817	4.556	0.275	0.102	0.765	0.940	0.546
C. V. (%)		8.0	14.3	5.3	2.4	4.9	10.3	6.4

* = Significance at .05
** = Significance at .01
*** = Significance at .001

[1]Mean squares have been multiplied by 1000 for presentation.

LITERATURE CITED

Ashenden, T. W., and I. A. D. Williams. 1980. Growth reductions in Lolium multiflorum Lam. and Phleum pratense L. as a result of SO_2 and NO_2 pollution. Environ. Pollut. (Ser. A) 21: 131-139.

Association of Official Analytical Chemists. 1980. Official Methods of Analysis. Thirteenth Edition. Association of Official Analytical Chemists, Washington, D. C. 1018p.

Barnes, R. L. 1972. Effects of chronic exposure to ozone on soluble sugar and ascorbic acid contents of pine seedlings. Can. J. Bot. 50: 215-219.

Bell, J. N. B., and W. S. Clough. 1973. Depression of yield in ryegrass exposed to sulphur dioxide. Nature 241: 47-48.

Ben-Ghedalia, D., and J. Miron. 1981. Effect of sodium hydroxide, ozone and sulphur dioxide on the composition and in vitro digestibility of wheat straw. J. Sci. Food Agric. 32: 224-228.

Bennett, J. H. 1969. Effects of ozone on leaf metabolism. Ph.D. dissertation, University of Utah, Salt Lake City, Utah.

Bennett, J. P., and V. C. Runeckles. 1977. Effects of low levels of ozone on plant competition. J. Appl. Ecol. 14: 877-880.

Bleasdale, J. K. A. 1952. Atmospheric pollution and plant growth. Nature 169: 376-370.

Brennan, E., and P. M. Halisky. 1970. Response of turfgrass cultivars to ozone and sulfur dioxide in the atmosphere. Phytopathology 60: 1544-1546.

Cowling, D. W., and M. J. Koziol. 1978. Growth of ryegrass (Lolium perenne L.) exposed to SO_2. I. Effects on photosynthesis and respiration. J. Exp. Bot. 29: 1029-1036.

Craker, L. E. 1972. Influence of ozone on RNA and protein content of Lemna minor L. Environ. Pollut. 3: 319-323.

Davis, C. R., D. R. Howell, and G. W. Morgan. 1966. Sulphur dioxide fumigations of range grasses native to southeastern Arizona. J. Range Manage. 19: 60-64.

Dugger, W. M., Jr., J. Koukol, and R. L. Palmer. 1966. Physiological and biochemical effects of atmospheric oxidants on plants. J. Air Pollut. Control Assoc. 16: 467-471.

Dugger, W. M., Jr., and R. L. Palmer. 1969. Carbohydrate metabolism in leaves of rough lemon as influenced by ozone. Proc. First Internat. Citrus Symp. 2: 711-715.

Faller, N. 1970-71. Effects of atmospheric SO_2 on plants. Sulphur Inst. J. 6: 5-7.

Ferenbaugh, R. W. 1978. Effects of prolonged exposure of Oryzopsis hymenoides to SO_2. Water, Air, Soil Pollut. 10: 27-31.

Flagler, R. B. 1980. The effect of ozone and sulfur dioxide on yield and quality of tall fescue. MS thesis, University of California, Riverside.

Flagler, R. B., and V. B. Youngner. 1980. The effect of ozone and sulfur dioxide on yield and quality of tall fescue. Agron. Abstr. : 124.

Heck, W. W., and J. A. Dunning. 1978. Response of oats to sulfur dioxide: interactions of growth temperature with exposure temperature or humidity. J. Air Pollut. Control Assoc. 28: 241-246.

Hill, A. C., S. Hill, C. Lamb, and T. W. Barrett. 1974. Sensitivity of native desert vegetation to SO_2 and to SO_2 and NO_2 combined. J. Air Pollut. Control Assoc. 24: 153-157.

Horsman, D. C., A. O. Nicholls, and D. M. Calder. 1980. Growth responses of *Dactylis glomerata*, *Lolium perenne*, *Phalaris aquatica* to chronic ozone exposure. Aust. J. Plant Physiol. 7: 511-517.

____________, T. M. Roberts, M. Lambert, and A. D. Bradshaw. 1979. Studies on the effect of sulphur dioxide on perennial ryegrass (*Lolium perenne* L.). I. Characteristics of fumigation system and preliminary experiments. J. Exp. Bot. 30: 485-493.

Lockyer, D. R., D. W. Cowling, and L. H. P. Jones. 1976. A system for exposing plants to atmospheres containing low concentrations of sulphur dioxide. J. Exp. Bot. 27: 397-409.

Menser, H. A., and H. E. Heggestad. 1966. Ozone and sulfur dioxide synergism: injury to tobacco plants. Science 153: 424-425.

Miller, P. R., J. R. Parameter, Jr., B. H. Flick, and C. W. Martinez. 1969. Ozone dosage response of ponderosa pine seedlings. J. Air Pollut. Control Assoc. 19: 435-438.

Murray, J. J., R. K. Howell, and A. C. Wilton. 1975. Differential response of seventeen *Poa pratensis* cultivars to ozone and sulfur dioxide. Plant Dis. Reptr. 59: 852-854.

Oshima, R. J. 1979. The impact of sulfur dioxide on a processing tomato stressed with chronic ambient ozone. Final Rep. ARB A7-141-30, California Air Resources Board, Sacramento, Calif. 83p.

Pandey, S. N., and D. N. Rao. 1978. Effects of coal-smoke sulphur dioxide pollution on the accumulation of certain minerals and chlorophyll content of wheat plants. Trop. Ecol. 19: 155-162.

Price, H., and M. Treshow. 1972. Effects of ozone on the growth and reproduction of grasses. Proc. Internat. Clean Air Conf. (Melbourne, Australia): 275-280.

Smith, D. 1969. Removing and analyzing total nonstructural carbohydrates from plant tissue. Wisc. Ag. Expt. Sta., Res. Rep. 41: 1-11.

Thompson, C. R., G. Kats, E. L. Pippen, and W. H. Isom. 1976. Effect of photochemical air pollution on two varieties of alfalfa. Environ. Sci. Technol. 10: 1237-1241.

Ting, I. P., and S. K. Mukerji. 1971. Leaf ontogeny as a factor in susceptibility to ozone: amino acid and carbohydrate changes during expansion. Amer. J. Bot. 58: 497-504.

Tingey, D. T. 1974. Ozone induced alterations in the metabolite pools and enzyme activities of plants. p. 40-57. In: Air Pollution Effects on Plant Growth, M. Dugger (ed.), Amer. Chem. Soc., Washington, D. C.

_____________, F. C. Fites, and C. Wickliff. 1973. Ozone alteration of nitrate reduction in soybean. Physiol. Plant. 29: 33-38.

_____________, R. A. Reinert, C. Wickliff, and W. W. Heck. 1973. Chronic ozone or sulfur dioxide exposures, or both, affect the early vegetative growth of soybean. Can. J. Plant Sci. 53: 875-879.

Wilton, A. C., J. J. Murray, H. E. Heggestad, and F. V. Juska. 1972. Tolerance and susceptibility of Kentucky bluegrass (*Poa pratensis* L.) cultivars to air pollution: in the field and in an ozone chamber. J. Environ. Qual. 1: 112-114.

Winner, W. E., and H. A. Mooney. 1980. Ecology of SO_2 resistance: III. Metabolic changes of C_3 and C_4 *Atriplex* species due to SO_2 fumigations. Oecologia 46: 49-54.

Youngner, V. B. 1975. Air pollution effects on turfgrasses. Calif. Turfgrass Cult. 25: 28-29.

_______________, and F. Nudge. 1980. Anatomical and physiological effects of air pollutants on turfgrasses. Proc. Third Internat. Turfgrass Res. Conf. (Munich, Germany): 155-163.

GLOSSARY

Ambient air	--	the outside air.
ANOVA	--	analysis of variation, a statistical procedure.
AOAC	--	Association of Official Analytical Chemists.
C.F.	--	crude fiber, inversely related to digestibility.
C.P.	--	crude protein, per cent nitrogen x 6.25.
gdw	--	gram dry weight.
interaction	--	when the combined effect of two or more independent treatments is greater or lesser than the sum of each treatment alone.
PAR	--	photosynthetically active radiation.
pphm	--	parts by volume of pollutant per hundred million parts by volume of air.
tiller	--	a grass shoot.
TNC	--	total nonstructural carbohydrates.

Appendix A

Fumigation I: Chamber characterization (7 August 1979).

Pacific Standard Time	PAR (μeinsteins m^{-2} sec^{-1}) Chamber 4			Temperature (°C)		Relative Humidity(%)	
	Ambient	Chamber	% Ambient	Ambient	Chamber	Ambient	Chamber
0500	4	3	84	20.0	21.7	56.0	68.5
0530	50	35	70				
0600	93	72	77	22.8	22.8	56.5	70.5
0630	230	210	91				
0700	670	630	94	30.6	30.0	55.0	71.0
0730	890	860	97				
0800	1100	980	89	35.0	33.3	54.0	56.0
0830	1320	1100	83				
0900	1450	1300	90	38.3	35.6	45.0	53.5
0930	1600	1300	81				
1000	1750	1450	83	41.1	37.8	39.5	53.5
1030	1950	1750	90				
1100	2000	1850	93	41.1	37.2	40.0	54.0
1130	2000	1800	90				
1200	1950	1700	87	37.2	36.1	37.0	53.0
1230	1950	1650	85				
1300	1800	1400	78	37.2	38.3	37.0	52.5
1330	1850	1500	81				
1400	1750	1500	86	35.6	37.8	37.5	54.0
1430	1600	1350	84				
1500	1400	1200	86	35.6	37.2	35.5	50.0
1530	1150	950	83				
1600	1000	950	95	31.1	33.9	39.0	53.0
1630	400	380	95				
1700	560	520	93	28.9	30.0	38.0	54.5
1730	300	280	93				
1800	150	130	87	28.9	30.0	41.5	53.5
1830	31	20	65				

Appendix B

Fumigation II: Chamber characterization (24 January 1980).

Pacific Standard Time	PAR (μeinsteins m^{-2} sec^{-1}) Chamber 2			Temperature (°C)		Relative Humidity(%)	
	Ambient	Chamber	% Ambient	Ambient	Chamber	Ambient	Chamber
0700	35	30	86	12.2	10.0	19.0	46.0
0730	80	60	75				
0800	360	75	21	15.6	18.3	22.5	43.0
0830	380	350	92				
0900	760	630	83	27.2	22.2	16.0	38.5
0930	960	960	100				
1000	1100	980	89	25.0	23.9	19.5	38.0
1030	1200	1000	83				
1130	1300	1050	81	28.3	25.6	18.5	38.5
1200	1350	1175	87				
1230	1350	1100	82	28.9	26.1	16.5	36.0
1300	1250	1050	84				
1330	1300	1075	83	26.1	25.6	17.0	35.0
1400	1225	1050	86				
1430	1100	800	73	25.0	25.6	16.0	35.0
1500	970	730	75				
1530	770	660	86	23.9	23.9	16.0	32.0
1600	550	470	86				
1630	380	340	90	22.8	21.1	16.5	31.0
1700	160	60	38				
1730	25	20	80	17.2	17.2	19.0	32.5

Appendix C

Discussion of Apparent Dose Discrepancies

If the actual ozone dosages recorded during a fumigation are considered for a given treatment level, e.g., 0% ambient air, a range of values is noted. That is, there are apparent dose discrepancies. We feel that these discrepancies between doses (within a block) in chambers of the same treatment level are due primarily to idiosyncracies of the sampling methodology and are not true differences of the magnitude indicated.

An excellent correlation exists between position in the sampling sequence and indicated ozone concentration, with higher concentrations being indicated later in the sampling sequence. This correlation holds within blocks for both experiments and has been noted by previous investigators using this facility (R. J. Oshima and K. W. Foster, personal communication).

Ozone "arrives" in Riverside on a fairly regular timetable and in a very regular pattern characterized by a gradual rise in the morning, a leveling-off or slight decrease at noon, followed by a sharp rise in the afternoon. This sharp rise in the afternoon usually occurs near the end of the six hour exposure period (after which time monitoring was shut off) meaning that treatments separated in time by sampling sequence appear different. This is one of the inherent dangers in trying to calculate an hourly average from a six minute sample period.

Periodic (usually weekly) checks were made to insure that treatment levels were indeed the same at the same instance. Levels proved to hold true throughout the experiment with only very minor fluctuations.

Appendix D

Fumigation I: peak ambient ozone concentrations (highest one-hour average) with corresponding chamber readings for the three days with highest ambient oxidant (ozone).

% Carbon Filtered	Chamber Number	pphm Ozone		
		6-26-79	7-8-79	9-7-79
Ambient	--	28	27	25
0	2	25	24	22
0	5	25	25	23
0	7	28	27	25
0	18	28	27	25
33	6	17	16	14
33	7	17	17	16
33	8	17	17	16
33	12	18	17	16
33	14	18	17	16
33	16	18	18	16
67	1	12	11	10
67	10	14	14	13
67	19	14	13	12
67	20	15	14	13
100	3	5	4	4
100	4	5	5	4
100	9	6	6	5
100	11	4	4	3
100	13	4	4	3
100	15	4	4	4
Time - PST:		1400	1600	1600

Appendix E

Fumigation II: peak ambient ozone concentrations (highest one-hour average) with corresponding chamber readings for the three days with highest ambient oxidant (ozone).

% Carbon Filtered	Chamber Number	pphm Ozone		
		10-24-79	10-25-79	10-27-79
Ambient	--	15	15	15
0	4	13	14	13
0	5	13	14	13
0	12	14	15	14
0	16	14	14	15
33	3	9	10	9
33	6	9	9	9
33	9	10	10	10
33	17	10	10	10
33	19	10	10	10
33	20	10	10	10
67	1	6	6	6
67	7	7	7	7
67	14	7	7	7
67	18	7	7	7
100	2	3	3	3
100	8	3	3	3
100	10	3	3	3
100	11	3	3	3
100	13	3	3	3
100	15	2	2	2
100				
Time - PST:		1500	1200	1500

Appendix F

Constituents of experimental soil tabulated per cubic yard of mix.
(UC Soil Mix III)

Soil (sandy loam)	16 cu. ft.
Canadian peat moss	12 cu. ft.
Single super phosphate	2.5 lbs.
KNO_3	4.0 oz.
K_2SO_4	4.0 oz.
Dolomite limestone	3.75 lbs.
Oystershell limestone	1.5 lbs.
Micronutrients	
Cu	30 ppm
Zn	10 ppm
Mn	15 ppm
Fe	15 ppm